

**Chapter 10 Water: essential to life****A1.**

Answers could include technological solutions, such as installing a water-saving shower head, dual-flush toilet and water-efficient washing machine or dishwasher, and planting drought-tolerant plants in the garden. Also, changing the way we use water, such as taking shorter showers, only using the machines with a full load and water the garden less frequently.

**A2.**

Water can be used as a coolant in energy production, such as in power plants. It is used to remove wastes or as a cleaning agent in industries ranging from food production to car manufacture. Farming activities use large volumes of water for irrigation.

**A3.**

**a** Properties that are special to water include:

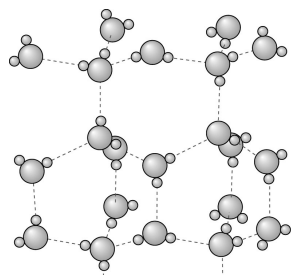
- high boiling temperature for its molecular size
- decrease in density on freezing
- high heat capacity
- high latent heat of fusion and evaporation for a substance of its molecular size

**b** The bond between H and O atoms in water is highly polar. As a result, hydrogen bonds exist between water molecules. Hydrogen bonds are stronger than other intermolecular bonds (although still weaker than the covalent intramolecular bonds) and so require more energy to break. Thus, water has a relatively high boiling temperature and heat of vaporisation.

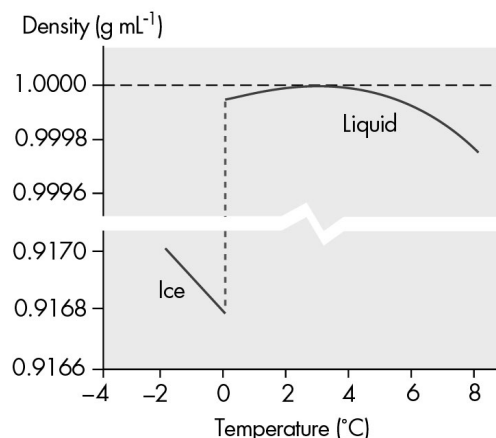
**A4.**

**a** The hydrogen bonds that hold water molecules in an ice lattice must be disrupted if ice is to melt.

**b**

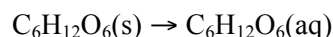
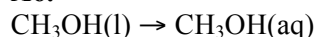
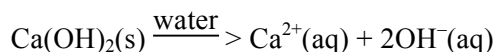
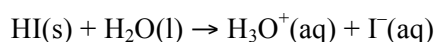


**c** As it freezes, water expands, unlike most liquids. This is because of hydrogen bonding. Each molecule is surrounded by four others in what is almost a crystal-type situation. (See graph below, which shows the variation in density of water with temperature.) Therefore, ice is less dense than liquid water, and it floats on liquid water. (For most liquids, the solid is denser than the liquid.) This is good news for fish, but not good news for travellers on the *Titanic*!

**A5.**

**a**  $E = SHC \times \text{mass} \times \Delta T = 4.2 \times 500 \times 67 = 140\,700 \text{ J} = 141 \text{ kJ}$

**b**  $E = SHC \times \text{mass} \times \Delta T = 0.13 \times 500 \times 67 = 436 \text{ J}$

**A6.****A7.****A9.**

A, B, D, E, H

**A10.**

A, C, D, E, F, H

**A11.**

**a**  $\text{Na}^+/\text{CO}_3^{2-}$  **b**  $\text{Ca}^{2+}/\text{NO}_3^-$  **c**  $\text{K}^+/\text{Br}^-$  **d**  $\text{Fe}^{3+}/\text{SO}_4^{2-}$  **e**  $\text{Cu}^{2+}/\text{Cl}^-$

**A12.**

- a** Nitrates are highly soluble in water. If found on Earth, they would dissolve in rainwater and wash into the oceans. Therefore, they are found only in areas of low rainfall.
- b** The high solubility of sodium, chloride, and sulfate ions results in them dissolving and flowing into the world's oceans.

**AE1.**

**a** solution **b** solution **c** colloid **d** colloid **e** suspension

**AE2.**

Boil off water and collect sediment.

**AE3.**

No, this must be a suspension. In a solution, the particles remain homogeneous over time; in a suspension they do not.

**Chapter review****A13.**

- a** Intermolecular forces are those between one molecule and other molecules. For water, these are hydrogen bonds. Intramolecular forces are those holding the atoms together within a molecule. For water, these are covalent bonds.
- b** Covalent bonds are stronger. Evidence for this is the high temperatures required to break the bonds between the oxygen and hydrogen atoms inside the water molecule and so decompose it into its constituent gases. Changing liquid water into gaseous water involves breaking hydrogen bonds to separate one molecule from another. The lower temperatures needed to do so indicate that hydrogen bonds are weaker.

**A14.**

- a** **i** The crystal lattice of ice is disrupted and molecules have greater freedom of movement. During this time, all solid ice is being converted to liquid water.
- ii** The added energy is taken up in overcoming the hydrogen bonds between molecules, separating the molecules to form a gas.
- b** Step 1: Find the temperature change.  $\Delta T = 100 - 25 = 75^\circ\text{C}$   
Step 2: Find the energy required. Energy =  $4.2 \times 200 \times 75 = 63\,000\text{ J} = 63\text{ kJ}$

**A15.**

Answer will vary for each person.

**A16.**

Water is such an effective solvent that it will dissolve many other solids, liquids and gases. Rainwater forming from clouds dissolves oxygen, carbon dioxide, dust, nitrogen oxides and sulfur oxide before it lands on the ground. It then dissolves soluble minerals as it flows down hillsides into streams and rivers while on its way to the oceans.

**A17.**

Water expands on freezing due to the formation of a regular lattice of water molecules held together by hydrogen bonds. The expanding ice may exert enough force to crack a glass bottle.

**A18.**

When water freezes in a confined space, such as a bottle or a metal pipe, its expansion can cause the bottle to break or the pipe to crack. The forces between particles in glass and in metal are strong; the tendency of water to expand must be a powerful one for it to overcome these strong forces and cause containers to break.

**A19.**

When an ionic solute, such as potassium bromide, dissolves in water, the following changes occur:

- the attraction between the positive potassium ions and the negative chloride ions is overcome
- hydrogen bonds between some water molecules are broken
- ion–dipole attractions are formed between the ions and water molecules

**A20.**

A solution is most likely to form when the polarity of bonding in the solute is similar to that in the solvent. The bonds formed between solute and solvent are then similar to those that existed between solute particles and between solvent particles. Water, being polar, is therefore a good solvent for ionic and polar substances. Likewise, a non-polar solvent will be a good solvent for non-polar solutes.

**A21.**

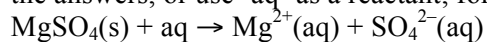
**a**  $\text{Cu}^{2+}(\text{aq}), \text{NO}_3^{-}(\text{aq})$       **b**  $\text{Zn}^{2+}(\text{aq}), \text{SO}_4^{2-}(\text{aq})$       **c**  $\text{NH}_4^{+}(\text{aq}), \text{PO}_4^{3-}(\text{aq})$

**A22.**

**a**  $\text{K}^{+}/\text{CO}_3^{2-}$     **b**  $\text{Pb}^{2+}/\text{NO}_3^{-}$     **c**  $\text{Na}^{+}/\text{OH}^{-}$     **d**  $\text{Na}^{+}/\text{SO}_4^{2-}$   
**e**  $\text{Mg}^{2+}/\text{O}_2$     **f**  $\text{Fe}^{2+}/\text{NO}_3^{-}$     **g**  $\text{K}^{+}/\text{S}^{2-}$     **h**  $\text{Fe}^{3+}/\text{NO}_3^{-}$

**A23.**

Note that it is accepted that the formula for water is not included in these equations. Use the format shown in the answers, or use ‘aq’ as a reactant; for example:



**a**  $\text{MgSO}_4(\text{s}) \xrightarrow{\text{water}} \text{Mg}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$     **b**  $\text{Na}_2\text{S}(\text{s}) \xrightarrow{\text{water}} 2\text{Na}^{+}(\text{aq}) + \text{S}^{2-}(\text{aq})$   
**c**  $\text{KOH}(\text{s}) \xrightarrow{\text{water}} \text{K}^{+}(\text{aq}) + \text{OH}^{-}(\text{aq})$     **d**  $(\text{CH}_3\text{COO})_2\text{Cu} \xrightarrow{\text{water}} 2\text{CH}_3\text{COO}^{-}(\text{aq}) + \text{Cu}^{2+}(\text{aq})$   
**e**  $\text{Li}_2\text{SO}_4(\text{s}) \xrightarrow{\text{water}} 2\text{Li}^{+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$

**A24.**

Ammonium sulfate, zinc nitrate and ethylene glycol are soluble. The axiom ‘like dissolves like’ is useful when working out solubility issues. Organic compounds, such as octane, will usually dissolve other organic compounds. Because water is a polar molecule, ionic or polar–covalent compounds tend to be soluble.

**A25.**

ethylene glycol

**A26.**

There are a number of possible answers to this question. Use the information in Table 10.4 (page 199). For example,  $\text{Na}_2\text{SO}_4$ ,  $\text{K}_2\text{SO}_4$  and  $(\text{NH}_4)_2\text{SO}_4$  are soluble whereas  $\text{CaSO}_4$ ,  $\text{BaSO}_4$  and  $\text{PbSO}_4$  are insoluble.

**A27.**

There are a number of possible answers to this question. Use the information in Table 10.4 (page 199). For example,  $\text{Na}_2\text{CO}_3$ ,  $\text{Li}_2\text{CO}_3$  and  $\text{K}_2\text{CO}_3$  are soluble whereas  $\text{CaCO}_3$ ,  $\text{MgCO}_3$  and  $\text{Ag}_2\text{CO}_3$  are insoluble.

**A28.**

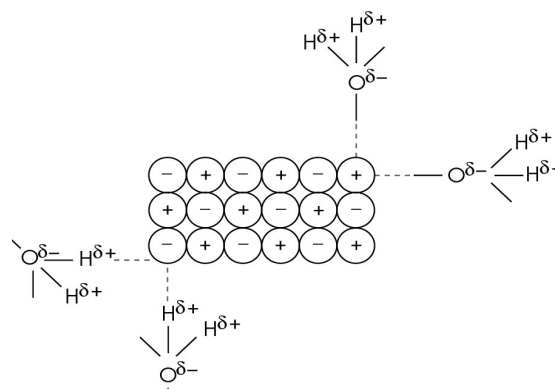
Sodium chromate, ammonium permanganate and hafnium nitrate are soluble. The axiom ‘like dissolves like’ is useful when working out solubility issues. Organic compounds, such as octane, will usually dissolve other organic compounds. Because water is a polar molecule, ionic or polar–covalent compounds tend to be soluble. Students intending to continue their studies in chemistry would do well to remember the solubility information in Table 10.4 (page 199).

**A29.**

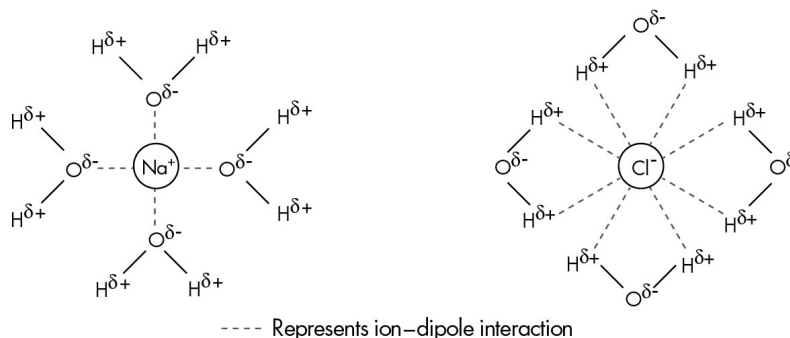
DDT is most likely non-polar because it is soluble in fats, which are non-polar, but is insoluble in polar water.

**A30.**

In solid sodium chloride, there is an electrostatic attraction between the positive sodium ions and the negative chloride ions. Water molecules, being polar, are attracted to the sodium ions and the positive ends of the water dipoles are attracted to the chloride ions. The formation of these ion–dipole attractions helps to pull the ions out of the crystal.



When an ion leaves the crystal, it is completely surrounded by water molecules. The ions are said to be hydrated. It is the energy released when ions are hydrated that compensates for the energy required to separate the ions in the lattice.



A31.

- |   |   |
|---|---|
| <p><b>a</b> <math>\text{Na}_3\text{PO}_4(\text{s}) \rightarrow 3\text{Na}^+(\text{aq}) + \text{PO}_4^{3-}(\text{aq})</math></p> <p><b>c</b> <math>\text{CuSO}_4(\text{s}) \rightarrow \text{Cu}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq})</math></p> <p><b>e</b> <math>(\text{CH}_3\text{COO})_2\text{Ca}(\text{s}) \rightarrow 2\text{CH}_3\text{COO}^-(\text{aq}) + \text{Ca}^{2+}(\text{aq})</math></p> <p><b>g</b> <math>\text{NaHCO}_3(\text{s}) \rightarrow \text{Na}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})</math></p> | <p><b>b</b> <math>\text{AlCl}_3(\text{s}) \rightarrow \text{Al}^{3+}(\text{aq}) + 3\text{Cl}^-(\text{aq})</math></p> <p><b>d</b> <math>\text{KOH}(\text{s}) \rightarrow \text{K}^+(\text{aq}) + \text{OH}^-(\text{aq})</math></p> <p><b>f</b> <math>(\text{NH}_4)_2\text{SO}_4(\text{s}) \rightarrow 2\text{NH}_4^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})</math></p> |
|---|---|

A32.

- a** Ammonia is a highly polar molecule and forms hydrogen bonds with water. It is therefore very soluble in water. Methane, however, is non-polar. Weak (dispersion) forces would occur only between methane and water, and these are unable to disrupt the stronger hydrogen bonds between water molecules. Therefore, methane does not dissolve in water.
- b** Glucose dissolves in water because it has very polar  $-\text{OH}$  groups that can form hydrogen bonds with water molecules. Sodium chloride is ionic; hence, there is an ion-dipole attraction between the ions and water. This is strong enough to overcome the attraction between the sodium ions and chloride ions in the solid NaCl lattice.

A33.

- |  |  |
|--|--|
| <p><b>a i</b> <math>\text{Na}^+, \text{K}^+, \text{Mg}^{2+}, \text{Ca}^{2+}, \text{Au}^+</math></p> <p><b>b i</b> Water has a very high specific heat capacity, which transfers heat energy from the warm equatorial region of Earth to the cooler temperate zones via ocean currents. This tends to moderate the climate of the planet and reduce temperature extremes.</p> <p><b>ii</b> Towns located close to the ocean tend to have cooler days and warmer nights than those further inland.</p> | <p><b>ii</b> <math>\text{Cl}^-, \text{CO}_3^{2-}, \text{PO}_4^{3-}, \text{Br}^-, \text{I}^-</math></p> |
|--|--|

A34.

Students' answers will vary but an example is:

- a i** Water dissolves the oxygen and carbon dioxide, which supports animal and plant life in aquatic ecosystems. Water is essential within all cells, to enable biological chemical processes to occur.
- ii** Water is a reactant in photosynthesis to produce sugars and oxygen:  
 $6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) + 6\text{O}_2(\text{g})$
- iii** Water's high heat capacity enables the oceans to store vast amounts of heat energy, which transfers heat from the hot tropics to the cooler, higher latitudes, thus moderating the Earth's temperatures to provide suitable conditions for life to exist. Water is also involved in moderating the temperature of individual organisms and thus avoid overheating (or cooling).
- b** Most of the world's water is locked up in ice at the poles, is too high in dissolved ions, such as those found in the oceans, or is found in inaccessible groundwater. Also, the rainfall across the planet is not distributed evenly.

A35.

Water is effective at dissolving ionic or polar substances.

- a** Nitrogen is not polar and is insoluble.
- b** Hydrogen peroxide will form hydrogen bonds with water and dissolve.
- c** Ethane is non-polar and insoluble.
- d** Ethanol has a polar  $-\text{OH}$  group, will form hydrogen bonds with water and dissolve.
- e** Strontium sulfate is ionic and will form ion-dipole bonds to dissolve in water.

## Chapter 11 Measuring solubility

A1.

a 32°C                      b 55°C                      c 68°C

A2.

a 84 g/100 g              b 36 g/100 g              c 38 g/100 g

A3.

a 25 g                      b 65 g                      c 100 g

A4.

a 42 g                      b 96 g                      c 184 g

A5.

14 g

A6.

No

A7.

35 g

A8.

Fizziness is a measure of carbon dioxide dissolved in water to produce weak carbonic acid. Gas solubility increases at lower temperatures, so more CO<sub>2</sub> is dissolved if stored in the refrigerator. When you drink lemonade, the warmth of your mouth makes some of the carbon dioxide come out of the solution. You feel a tingling sensation in your mouth, especially when the lemonade is cold and the temperature difference between it and your mouth is greater.

A9.

a concentration (w/v) =  $\frac{\text{mass}}{\text{litre}} = \frac{5 \text{ g}}{200 \times 10^{-3} \text{ L}} = 2.5 \text{ g L}^{-1}$                       b 0.06 g L<sup>-1</sup>

A10.

Remember that the formula for amount of substance in solution is  $n = c \times V$  (where  $n$  is the number of mole,  $c$  the concentration in mol/L and  $V$  the volume of the solution in litres).

a  $n = 0.22 \times 0.10 = 0.022 \text{ mol}$                       b  $n = 0.22 \times 0.010 = 0.0022 \text{ mol}$   
 c  $n = 0.015 \times 0.0156 = 2.34 \times 10^{-4} \text{ mol}$                       d  $n = 0.000 \text{ 78 mol or } 7.8 \times 10^{-4} \text{ mol}$

A11.

The word *molarity* is often used in questions to do with concentration. In such cases, the units are always mol/L and are calculated using the re-arranged mol formula,  $c = n/V$  where the Volume is in Litres.

a  $c = 0.48 \text{ M}$                       b  $c = 8 \times 10^{-2} \text{ M}$                       c  $c = \frac{1.23}{4.1} = 0.30 \text{ M}$                       d  $c = 1.9 \times 10^{-3} \text{ M}$

A12.

The molar concentration can be calculated by first calculating the number of mole, then using the relation  $n = cV$  to calculate the concentration.

a  $n(\text{CaCl}_2) = \frac{m}{M} = \frac{1.223}{75.5} = 0.0162 \text{ mole then } c(\text{CaCl}_2) = \frac{n}{V} = \frac{0.0162}{1.55\text{L}} = 0.0105 \text{ M}$   
 b  $n(\text{Ba}(\text{NO}_3)_2) = \frac{m}{M} = \frac{0.521 \text{ g}}{261.3 \text{ g/mol}^{-1}} = 0.001 \text{ 99 mole then } c(\text{Ba}(\text{NO}_3)_2) = \frac{n}{V} = \frac{0.00199 \text{ mol}}{22.0 \times 10^{-3} \text{ L}} = 0.0906 \text{ M}$   
 c  $n(\text{Na}_3\text{PO}_4) = \frac{m}{M} = \frac{1.61 \text{ g}}{163.9 \text{ g/mol}^{-1}} = 0.009 \text{ 82 mole then } c(\text{Na}_3\text{PO}_4) = \frac{n}{V} = \frac{0.00982 \text{ mol}}{45.0 \times 10^{-3} \text{ L}} = 5.99 \times 10^{-3} \text{ M}$   
 d 20.0 L of solution, containing  $4.07 \times 10^{-3} \text{ mol}$  of KF then  $c(\text{KF}) = \frac{n}{V} = \frac{4.07 \times 10^{-3} \text{ mol}}{20.0 \times 10^{-3} \text{ L}} = 0.204 \text{ M}$

A13.

Dilution questions are best answered using the formula  $c_1V_1 = c_2V_2$ , where  $c$  is the concentration in mol/L and  $V$  is the volume of the solution. Each of the volume units needs to be the same, although not necessarily litres.

a  $c_2 = 1.2 \times 1.625 \times 10^{-3} = 0.4 \text{ M}$                       Note that  $V_2$  was 15 mL because the 10 mL was added to the 5 mL.  
 b  $c_2 = 0.1 \times 0.75 = 0.075 \text{ M}$                       Note that  $V_2$  was 4 L because the 1 L was added to the 3 L.  
 c  $c_2 = 0.50 \times 0.05 = 0.025 \text{ M}$                       Note that  $V_2$  was 100 mL because the 5 mL was added to the 95 mL.  
 d 20 g/L Na<sub>2</sub>CO<sub>3</sub> = 0.19 mol/L (0.19 M) then  $c_2 = \frac{40.0 \times 0.19}{250} = 0.03 \text{ M}$

AE1.

0.9% w/v = 0.9 g of solute (sodium chloride) present in 100 mL of the solution.

There is 200 mL of the solution, so the amount of sodium chloride is:  $= (200 \text{ mL} \div 100 \text{ mL}) \times 0.9 = 1.8 \text{ g}$

**AE2.**

37% v/v = 37 mL of alcohol (ethanol) in 100 mL of the gin. The 'shot' is 50 mL, so the amount of ethanol present is:  $= 37 \text{ mL} \times (50 \text{ mL} \div 100 \text{ mL}) = 18.5 \text{ mL}$

**AE3.**

20% w/v = 20 g of solute (sugar) present in 100 mL of solution.

There is 60 mL of the solution, so the amount of sugar is:  $= (60 \text{ mL} \div 100 \text{ mL}) \times 20 \text{ g} = 12 \text{ g}$

**AE4.**

- a**  $m(\text{chloride}): 0.2 \times 220 = 44 \text{ mg}$   $m(\text{calcium}): 0.2 \times 50 = 10 \text{ mg}$   
 $m(\text{magnesium}): 0.2 \times 45 = 9 \text{ mg}$   $m(\text{potassium}): 0.2 \times 6 = 1.2 \text{ mg}$
- b** Molar concentration = amount(mol)/L solution = mass concentration (g/L)  $\div$  molar mass ( $\text{g mol}^{-1}$ )  
 $c(\text{chloride}): 0.220 \div 35.45 = 0.062 \text{ mol/L}$   $c(\text{calcium}): 0.050 \div 40.08 = 0.0013 \text{ mol/L}$   
 $c(\text{magnesium}): 0.045 \div 24.31 = 0.0019 \text{ mol/L}$   $c(\text{potassium}): 0.006 \div 39.10 = 0.00015 \text{ mol/L}$

**AE5.**

- a** Mass of cadmium present is:  $= \text{mass of water (g)} \times \text{concentration of cadmium (g/g water)}$   
 $= 100 \times 1000 \text{ g} \times 5 \text{ } \mu\text{g/g} = 5 \times 10^5 \text{ } \mu\text{g}$
- b**  $1 \text{ mg} = 1000 \text{ } \mu\text{g}$ , so  $5 \times 10^5 \text{ } \mu\text{g} = (5 \times 10^5) \div 1000 = 5 \times 10^2 \text{ mg}$
- c**  $1 \text{ g} = 1000 \text{ mg}$ , so  $5 \times 10^2 \text{ mg} = (5 \times 10^2) \div 1000 = 0.5 \text{ g}$

**Chapter review****A14.**

- a** **i** At 80°C all of the 50 g of copper sulfate will dissolve.  
**ii** At 20°C only 22 g of the copper sulfate will dissolve.
- b** **i** At 80°C all of the 5 g of sodium chloride will dissolve.  
**ii** At 20°C all of the 5 g of sodium chloride will dissolve.
- c** **i** No charcoal will dissolve at 80°C.  
**ii** No charcoal will dissolve at 20°C.
- d** Some of the mixture should be added to water at 80°C. The amount of water should be just enough to dissolve all the copper sulfate. The sodium chloride will also dissolve but the charcoal will not. This mixture should be filtered at 80°C. Filtration will leave the charcoal in the filter paper and the sodium chloride and copper sulfate in the filtrate. As the filtrate cools, some of the copper sulfate will crystallise out of solution. A very small amount of NaCl may also crystallise, depending on the amount of water present. The copper sulfate can then be filtered from the solution. It can then be redissolved and recrystallised to remove any traces of sodium chloride.

**A15.**

From the temperature axis, draw an imaginary line from the specified temperature. The solubilities can then be read from the vertical axis.

- a** 60 g/100 g      **b**      **i**      lead nitrate      **ii**      potassium nitrate
- c** mass of ammonium chloride that will dissolve in 750 g of water  $= 0.32 \times 750 = 240 \text{ g}$
- d** mass of water needed to dissolve 76 g of sodium chloride  $= 2 \times 100 = 200 \text{ g}$
- e** **i** saturated      **ii** supersaturated      **iii** saturated      **iv** unsaturated
- f** Mass of potassium nitrate that will dissolve in 50 g of water  $= 0.5 \times 30 = 15 \text{ g}$   
 $\therefore$  Additional mass of potassium nitrate needed  $= 5 \text{ g}$
- g** All 60 g of ammonium chloride will be dissolved.  
 So about 26 g of ammonium would crystallise out of solution (assuming that it is not supersaturated).
- h** Mass of potassium nitrate that will dissolve in 50 g of water  $= 0.50 \times 84 = 42 \text{ g}$   
 Mass of potassium nitrate which will dissolve in 50 g of water  $= 0.50 \times 30 = 15 \text{ g}$   
**i** Mass of potassium nitrate dissolved  $= 15 \text{ g}$   
**ii** Mass of potassium nitrate crystallised out of solution  $= 42 - 15 = 27 \text{ g}$
- i** **i** 45 g of potassium nitrate in 50 g of water corresponds to  $45 \times 2 \text{ g}$  of the salt in 100 g of water.  
**ii** 1.7 g of potassium nitrate in 10 g of water corresponds to  $1.7 \times 10 \text{ g}$  of the salt in 100 g of water.

**A16.**

- a** A: saturated; B: supersaturated; C: unsaturated  
**b** **i** crystals form **ii** crystals form

**A17.**

- a** Concentration of salt =  $0.20 \times 1000 = 200 \text{ g L}^{-1}$   
**b** Concentration of sugar =  $0.083 \times 1000 = 83 \text{ g L}^{-1}$   
**c** Concentration of glucose =  $0.013 \times 1000 = 13 \text{ g L}^{-1}$   
**d** Concentration of  $\text{KNO}_3$  =  $0.21 \times 1000 = 210 \text{ g L}^{-1}$

**A18.**

200 mL of solution with a concentration of 10 g/L would need  $= \frac{200}{1000} = \frac{1}{5}$  the mass, hence, 2 g of fertiliser would be needed.

**A19.**

- a** The concentration of each solution is 0.20 M.  
**b** The first volume (25 mL) must be converted to litres, and so is 0.025 L.  
 For the first solution:  $c = 0.010/0.025 = 0.400 \text{ M}$  For the second solution:  $c = 0.678 \text{ M}$   
 The second solution was more concentrated.  
**c** Regarding the first solution:  $[\text{HCl}] = 1.1 \text{ M}$   
 Regarding the second solution:  $n(\text{HCl molecules}) = 0.050 \text{ mol}$  so  $[\text{HCl}] = 0.42 \text{ M}$   
 The first solution is more concentrated.  
**d** The first solution is 0.015 M. Regarding the second solution:  
 $n(\text{Mg}(\text{OH})_2) = 0.0300 \text{ mol}$  so  $[\text{Mg}(\text{OH})_2] = 0.0600 \text{ M}$   
 The second solution is more concentrated.

**A20.**

$n(\text{CH}_3\text{COOH}) = 0.067 \text{ mol}$  so  $c(\text{CH}_3\text{COOH}) = 0.667 \text{ M}$

**A21.**

The formula for amounts of substance in solution is  $n = c \times V$  (where  $n$  is the amount in mole,  $c$  the concentration in mol/L and  $V$  the volume of the solution in litres). The word molarity is often used in questions to do with concentration. In such cases, the units are always mol/L.

- a**  $n = 0.25 \times 3.0 = 0.75 \text{ mol}$  **b**  $n = 0.185 \times 2.5 = 0.46 \text{ mol}$   
**c**  $n = 0.0250 \times 0.100 = 2.50 \times 10^{-3} \text{ mol}$  **d**  $n = (0.5 \times 0.092) + (0.2 \times 0.135) = 0.07 \text{ mol}$   
 (Note: the two calculations are done separately and the results then added together. Also, the volume units are in mL, and so we convert to litres.)

**A22.**

- a**  $n = cV = 1.5 \text{ M} \times 200 \times 10^{-3} \text{ L} = 0.300 \text{ mol}$  then  $m(\text{NaOH}) = n \times M = 0.300 \times 40.0 = 12 \text{ g}$   
**b**  $n = cV = 0.99 \text{ M} \times 50 \times 10^{-3} \text{ L} = 0.046 \text{ mol}$  then  $m(\text{K}_2\text{CO}_3) = n \times M = 0.046 \times 138.2 = 6.84 \text{ g}$   
**c**  $n = cV = 1.2 \text{ M} \times 0.1 = 0.120 \text{ mol}$  then  $m(\text{NH}_3) = n \times M = 0.120 \times 17 = 2.04 \text{ g}$   
**d**  $n = cV = 0.50 \text{ M} \times 20 \times 10^{-3} \text{ L} = 0.01 \text{ mol}$  then  $m(\text{AgNO}_3) = n \times M = 0.01 \times 169.9 = 1.7 \text{ g}$   
**e**  $n = cV = 5.0 \text{ M} \times 500 \times 10^{-3} \text{ L} = 2.5 \text{ mol}$  then  $m(\text{CuCl}_2) = n \times M = 2.5 \times 134.5 = 336 \text{ g}$

**A23.**

These are two-step questions involving  $n = cV$ , where  $c$  is the concentration of the solution in  $\text{mol L}^{-1}$  and  $V$  is the volume in litres. Then use  $m = nM$ , where  $M$  is the molar mass in  $\text{g mol}^{-1}$ . Use a periodic table to work out the molar masses.

- a**  $M(\text{KCl}) = 74.6 \text{ g mol}^{-1}$  so  $n(\text{KCl}) = 0.560 \times 0.140 = 0.0784 \text{ mol}$  and  $m(\text{KCl}) = 0.0784 \times 74.6 = 5.85 \text{ g}$   
**b** 546 g **c** 0.78 g **d** 4.69 g **e** 84.8 g

**A24.**

$$V = \frac{n}{c} = \frac{0.500}{1.24} = 0.40 \text{ L} = 400 \text{ mL}$$

**A25.**

From the formula, the number of mole of sulfate is 3 times the number of mole of  $\text{Fe}_2(\text{SO}_4)_3$ . Therefore, the



concentration of the  $\text{Fe}_2(\text{SO}_4)_3$  is  $\frac{1}{3}$  of  $c(\text{Fe}_2(\text{SO}_4)_3)$ ; that is,  $\frac{1}{3} \times 0.183 \text{ M}$ .

The symbol 'm' is used to represent the prefix 'milli'. There are 1000 milligrams in 1 gram.

Step 1:  $0.075 \text{ g} = 75 \text{ mg}$ .

Step 2: Concentration = mass of solute (mg)/volume of solution (L) =  $50 \text{ mg/L}$

### A27.

With any dilution process, the amount of solute does not change.

$$\therefore \text{mass of Na}_2\text{CO}_3 \text{ initially} = \frac{5.2}{1000} \times 120 = 0.624 \text{ g}$$

$$\therefore \text{new concentration of Na}_2\text{CO}_3 = \frac{0.624}{3000} \times 1000 = 0.21 \text{ g/L}$$

### A28.

Dilution questions are best answered by using the formula  $c_1V_1 = c_2V_2$ , where  $c$  is the concentration in mol/L and  $V$  is the volume of the solution. Each of the volume units needs to be the same, although not necessarily

$$\text{litres } V_2 = 0.30 \times \frac{250}{10} = 7.5 \text{ mL}$$

### A29.

Use  $c_1V_1 = c_2V_2$ , where  $c$  refers to the concentration or molarity in  $\text{mol L}^{-1}$  and  $V$  is the volume in litres.

**a**  $c_2 = 0.20 \text{ M}$

**b**  $n_1 = 0.40 \times 0.025 = 0.01 \text{ mol}$   $n_2 = 1.2 \times 0.050 = 0.06 \text{ mol}$

As 25 mL is added to 50 mL,  $V_{\text{final}} = 75 \text{ mL} = 0.075 \text{ L}$  So,  $c_{\text{final}} = \frac{0.01 + 0.06}{0.075} = 0.93 \text{ M}$

### A30.

The concentration of chloride ions is twice the concentration of the  $\text{CaCl}_2$ .

Therefore,  $c(\text{Cl}^-) = 2 \times c(\text{CaCl}_2) = 2 \times 0.024 \text{ M} = 0.048 \text{ M}$

### A31.

$V_1 = 0.5 \text{ mL}$  of the original (0.500 M) NaCl solution required

### A32.

$$c_1V_1 = c_2V_2 \text{ so } V_2 = \frac{c_1V_1}{c_2} = 66.7 \text{ mL} \quad \therefore \text{Volume to be added} = 66.7 - 25 = 41.7 \text{ mL}$$

### A33.

$$c_2 = \frac{c_1V_1}{V_2} = \frac{0.0500 \times 30.0}{50.0} = 0.030 \text{ M} \quad \text{The concentration of Na}^+ \text{ ions is twice that of the Na}_2\text{CO}_3 = 0.060 \text{ M.}$$

You are probably familiar with the term *per cent*. It literally means 'per hundred' or 'out of a hundred'. The symbol % is used for per cent. So 1% of 200 is 2, so 2 g of the salt will be needed.

### A34.

**a**  $c = 0.63 \text{ M}$

**b**  $c = 5.0 \times 10^{-3} \text{ M}$

**c** Dilution questions are best answered by applying the formula  $c_1V_1 = c_2V_2$ , where  $c$  is the concentration in mol/L and  $V$  is the volume of the solution. Each of the volume units needs to be the same, although not necessarily litres. The total volume =  $200 + 40 = 240 \text{ mL} = 0.240 \text{ L}$

So  $c_2 = 40 \times \frac{0.25}{240} = 0.042 \text{ M}$  (Note that  $V_2$  is 240 mL because the 200 mL is added to the 40 mL.)

### A35.

**a**  $c = 0.20 \text{ M}$

**b**  $c = 0.20 \text{ M}$

**c**  $c = 0.44 \text{ M}$

**d**  $c = 0.46 \text{ M}$

(Note: the volume units are in mL, and so we convert to litres.)

### A36.

**a i**  $n(\text{AlCl}_3) = 0.050 \times 0.025 = 0.0013 \text{ mol}$  (or  $1.3 \times 10^{-3} \text{ mol}$ )

**ii**  $n(\text{Al}^{3+}) = n(\text{AlCl}_3) = 0.050 \times 0.025 = 0.0013 \text{ mol}$  (or  $1.3 \times 10^{-3} \text{ mol}$ )

**iii**  $n(\text{Cl}^-) = 3 \times n(\text{AlCl}_3) = 3 \times 0.050 \times 0.025 = 0.0038 \text{ mol}$  (or  $3.8 \times 10^{-3} \text{ mol}$ )



$$\text{iv } n(\text{ions}) = n(\text{Al}^{3+}) + n(\text{Cl}^-) = 0.0013 + 0.0038 = 0.0051$$

$$\text{Number of ions} = 0.0051 \times N_A = 3.0 \times 10^{21}$$

- b**
- i**  $n(\text{AlCl}_3) = 0.015 \times 0.0326 = 0.00049 \text{ mol (or } 4.9 \times 10^{-4} \text{ mol)}$
  - ii**  $n(\text{Al}^{3+}) = n(\text{AlCl}_3) = 0.015 \times 0.0326 = 0.00049 \text{ mol (or } 4.9 \times 10^{-4} \text{ mol)}$
  - iii**  $n(\text{Cl}^-) = 3 \times n(\text{AlCl}_3) = 3 \times 0.015 \times 0.0326 = 0.0015 \text{ mol (or } 1.5 \times 10^{-3} \text{ mol)}$
  - iv**  $n(\text{ions}) = n(\text{Al}^{3+}) + n(\text{Cl}^-) = 0.00049 + 0.0015 = 0.0020$
- $$\text{Number of ions} = 0.0020 \times N_A = 1.2 \times 10^{21}$$

**A37.**

- Step 1** Dilution questions are best answered by using the formula  $c_1V_1 = c_2V_2$ , where  $c$  is the concentration in mol/L and  $V$  is the volume of the solution. Each of the volume units needs to be the same, although not necessarily litres.  $c_2 = 0.19 \text{ M}$
- Step 2** Remember that the formula for amounts of substance in solution is  $n = c \times V$  (where  $n$  is the amount in mole,  $c$  the concentration in mol/L and  $V$  the volume of the solution in litres).
- $$n = 0.19 \times 0.040 = 0.0075 \text{ mol}$$

**Chapter 12 Water: removing dissolved solutes****A1.**

Chemicals containing the ions  $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{NH}_4^+$  and  $\text{NO}_3^-$  almost never form a precipitate.

- a**
- i**  $\text{MgS(s)}$
  - ii**  $\text{AgCl(s)}$
  - iii**  $\text{Al(OH)}_3\text{(s)}$
  - iv**  $\text{Mg(OH)}_2\text{(s)}$
- b**
- i**  $\text{K}_2\text{S(aq)} + \text{MgCl}_2\text{(aq)} \rightarrow \text{MgS(s)} + 2\text{KCl(aq)}$
  - ii**  $\text{CuCl}_2\text{(aq)} + 2\text{AgNO}_3\text{(aq)} \rightarrow 2\text{AgCl(s)} + \text{Cu(NO}_3)_2\text{(aq)}$
  - iii**  $\text{AlCl}_3\text{(aq)} + 3\text{KOH(aq)} \rightarrow \text{Al(OH)}_3\text{(s)} + 3\text{KCl(aq)}$
  - iv**  $\text{MgSO}_4\text{(aq)} + 2\text{NaOH(aq)} \rightarrow \text{Mg(OH)}_2\text{(s)} + \text{Na}_2\text{SO}_4\text{(aq)}$

**A2.**

- a**
- i**  $\text{AgNO}_3\text{(aq)} + \text{NaCl(aq)} \rightarrow \text{AgCl(s)} + \text{NaNO}_3\text{(aq)}$
  - ii**  $\text{Ag}^+\text{(aq)} + \text{Cl}^-\text{(aq)} \rightarrow \text{AgCl(s)}$
  - b**
  - i**  $\text{CuSO}_4\text{(aq)} + \text{Na}_2\text{CO}_3\text{(aq)} \rightarrow \text{CuCO}_3\text{(s)} + \text{Na}_2\text{SO}_4\text{(aq)}$
  - ii**  $\text{Cu}^{2+}\text{(aq)} + \text{CO}_3^{2-}\text{(aq)} \rightarrow \text{CuCO}_3\text{(s)}$
  - c**
  - i**  $(\text{NH}_4)_2\text{SO}_4\text{(aq)} + \text{BaCl}_2\text{(aq)} \rightarrow \text{BaSO}_4\text{(aq)} + 2\text{NH}_4\text{Cl(aq)}$
  - ii**  $\text{SO}_4^{2-}\text{(aq)} + \text{Ba}^{2+}\text{(aq)} \rightarrow \text{BaSO}_4\text{(aq)}$
  - d**
  - i**  $\text{K}_2\text{S(aq)} + \text{Pb(NO}_3)_2\text{(aq)} \rightarrow \text{PbS(s)} + 2\text{KNO}_3\text{(aq)}$
  - ii**  $\text{S}^{2-}\text{(aq)} + \text{Pb}^{2+}\text{(aq)} \rightarrow \text{PbS(s)}$
  - e**
  - i**  $3\text{CaCl}_2\text{(aq)} + 2\text{Na}_3\text{PO}_4\text{(aq)} \rightarrow 6\text{NaCl(aq)} + \text{Ca}_3(\text{PO}_4)_2\text{(s)}$
  - ii**  $3\text{Ca}^{2+}\text{(aq)} + 2\text{PO}_4^{3-}\text{(aq)} \rightarrow \text{Ca}_3(\text{PO}_4)_2\text{(s)}$
  - f**
  - i**  $2\text{NaOH(aq)} + \text{Pb(NO}_3)_2\text{(aq)} \rightarrow 2\text{NaNO}_3\text{(aq)} + \text{Pb(OH)}_2\text{(s)}$
  - ii**  $2\text{OH}^-\text{(aq)} + \text{Pb}^{2+}\text{(aq)} \rightarrow \text{Pb(OH)}_2\text{(s)}$

**A3.**

- a** False. When water is distilled, the water boils off to form a vapour, leaving the ions in the original solution.
- b** False. Reverse osmosis involves forcing water, under pressure, to pass from a region of high salt concentration to one of lower salt concentration.
- c** True
- d** False. Water supplies are generally treated with chlorine to ensure that harmful bacteria are destroyed before the water is made available for drinking.

**A4.**

- a** flocculation                      **b** filtration                      **c** ion exchange
- d**  $\text{Ca}^{2+}$  and  $\text{HCO}_3^-\text{(aq)}$                       **e** bent or V-shaped

**A5.**

- a** Maximum fluoride levels are  $1.2 \text{ ppm (mg L}^{-1}\text{)}$ .
- b** Excessive fluoride causes mottling of tooth enamel and a tendency to brittle bones. There is some concern that, as a cumulative poison, it will also cause damage to the central nervous system.

**AE1.**

- a**  $1 \text{ } \mu\text{g/g} = \mu\text{g} \times \frac{1 \text{ mg}}{1000 \mu\text{g}} \times \frac{1}{\text{g}} \times \frac{1000 \text{ g}}{1 \text{ L}} = 1 \text{ mg/L}$

Ion	Concentration (mg/L)	Maximum allowable (mg/L)	Discharge permitted?
Copper	20	10	No
Calcium	2	?	Yes
Iron	55	30	No
Lead	85	10	No
Zinc	3	10	Yes

- b**
- i** Each concentration will now be  $0.2 \times$  old concentration.  
Copper:  $0.2 \times 20 = 4$  mg/L; calcium:  $0.2 \times 2 = 0.4$  mg/L; iron:  $0.2 \times 55 = 11$  mg/L; lead:  $0.2 \times 85 = 17$  mg/L; zinc:  $0.2 \times 3 = 0.6$  mg/L.
  - ii** Lead cannot be discharged, even after dilution. (17 mg/L is greater than the allowed maximum of 10 mg/L.)
  - iii** The desire is to precipitate the lead ions, so a compound containing sulphide ( $S^{2-}$ ) or phosphate ( $PO_4^{3-}$ ) would be best.

### Chapter review

#### A6.

	NaOH	KBr	NaI	MgSO <sub>4</sub>	AgNO <sub>3</sub>	BaCl <sub>2</sub>
Pb(NO <sub>3</sub> ) <sub>2</sub>	Pb(OH) <sub>2</sub>	PbBr <sub>2</sub>	PbI <sub>2</sub>	PbSO <sub>4</sub>		PbCl <sub>2</sub>
KI					AgI	BaI <sub>2</sub>
CaCl <sub>2</sub>	Ca(OH) <sub>2</sub>			CaSO <sub>4</sub>	AgCl	
Na <sub>2</sub> CO <sub>3</sub>				MgCO <sub>3</sub>	AgCO <sub>3</sub>	BaCO <sub>3</sub>
Na <sub>2</sub> S				MgS	Ag <sub>2</sub> S	BaS

#### A7.

From the Solubility Table (see page 199 in the textbook),  $Fe^{2+}$  would precipitate in the presence of  $PO_4^{3-}$  and  $S^{2-}$  to produce  $Fe_3(PO_4)_2$  and  $FeS$ .

#### A8.

- a** silver carbonate      **b** lead(II) hydroxide      **c** magnesium sulfide      **d** none

#### A9.

- a**  $NH_4Cl(aq) + AgNO_3(aq) \rightarrow NH_4NO_3(aq) + AgCl(s)$        $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$   
**b**  $Fe(NO_3)_2(aq) + Na_2S(aq) \rightarrow FeS(s) + 2NaNO_3(aq)$        $Fe^{2+}(aq) + S^{2-}(aq) \rightarrow FeS(s)$   
**c**  $Fe(NO_3)_2(aq) + 2KOH(aq) \rightarrow 2KNO_3(aq) + Fe(OH)_2(s)$        $Fe^{2+}(aq) + 2OH^-(aq) \rightarrow Fe(OH)_2(s)$   
**d**  $CuSO_4(aq) + 2NaOH(aq) \rightarrow Cu(OH)_2(s) + Na_2SO_4(aq)$        $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$   
**e**  $Ba(NO_3)_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2NaNO_3(aq)$        $Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

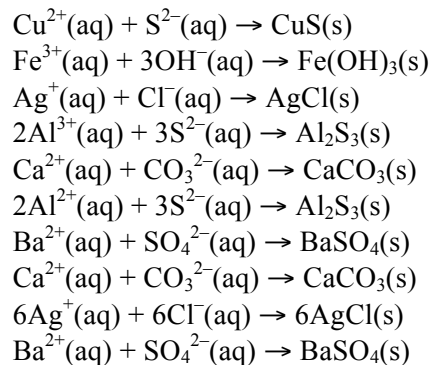
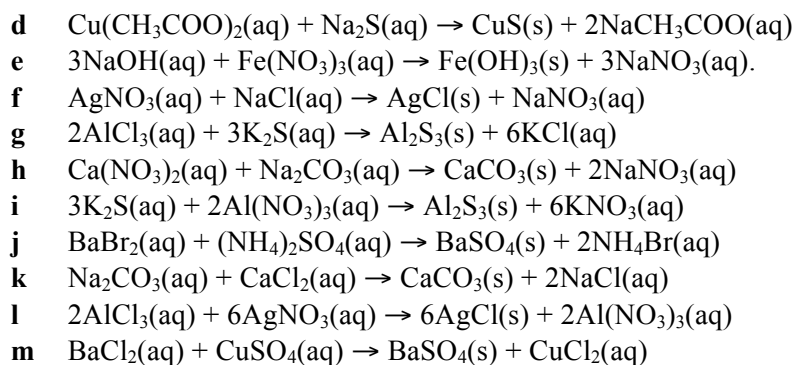
#### A10.

- a**  $CuSO_4(aq) + Na_2CO_3(aq) \rightarrow CuCO_3(s) + Na_2SO_4(aq)$        $Cu^{2+}(aq) + CO_3^{2-}(aq) \rightarrow CuCO_3(s)$   
spectator ions:  $Na^+$ ,  $SO_4^{2-}$   
**b**  $AgNO_3(aq) + KCl(aq) \rightarrow AgCl(s) + KNO_3(aq)$        $Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$   
spectator ions:  $K^+$ ,  $NO_3^-$   
**c**  $Na_2S(aq) + Pb(NO_3)_2(aq) \rightarrow PbS(s) + 2NaNO_3(aq)$        $Pb^{2+}(aq) + S^{2-}(aq) \rightarrow PbS(s)$   
spectator ions:  $Na^+$ ,  $NO_3^-$   
**d**  $FeCl_3(aq) + 3NaOH(aq) \rightarrow Fe(OH)_3(s) + 3NaCl(aq)$        $Fe^{3+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(s)$   
spectator ions:  $Na^+$ ,  $Cl^-$   
**e**  $Fe_2(SO_4)_3(aq) + 6KOH(aq) \rightarrow 2Fe(OH)_3(s) + 3K_2SO_4(aq)$        $Fe^{3+}(aq) + 3OH^-(aq) \rightarrow Fe(OH)_3(s)$   
spectator ions:  $K^+$ ,  $SO_4^{2-}$

#### A11.

When writing ionic equations, do not show the ions still present in the solution. Table 10.4 (page 199) is a useful guide to this work. The ions  $Na^+$ ,  $NH_4^+$  and  $NO_3^-$  are almost never involved in ionic equations.

- a**  $MgSO_4(aq) + Na_2S(aq) \rightarrow MgS(s) + Na_2SO_4(aq)$        $Mg^{2+}(aq) + S^{2-}(aq) \rightarrow MgS(s)$   
**b**  $2KOH(aq) + Cu(NO_3)_2(aq) \rightarrow Cu(OH)_2(s) + 2KNO_3(aq)$        $Cu^{2+}(aq) + 2OH^-(aq) \rightarrow Cu(OH)_2(s)$   
**c**  $2(NH_4)_3PO_4(aq) + 3ZnSO_4(aq) \rightarrow Zn_3(PO_4)_2(s) + 3(NH_4)_2SO_4(aq)$   
 $3Zn^{2+}(aq) + 2PO_4^{3-}(aq) \rightarrow Zn_3(PO_4)_2(s)$

**A12.**

A solution of any soluble lead salt mixed with a solution of any soluble iodide will give a precipitate of lead iodide; for example, lead nitrate and potassium iodide.

**A13.**

The chemical treatment of drinking water is covered in great detail in Chapter 12.

Formation of floc:  $\text{Al}^{3+}(\text{aq}) + 3\text{OH}^{-}(\text{aq}) \rightarrow \text{Al}(\text{OH})_3(\text{s})$

Removal of  $\text{Ca}^{2+}$  ions from solution:  $\text{Ca}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{CaCO}_3(\text{s})$

Removal of  $\text{Mg}^{2+}$  ions from solution:  $\text{Mg}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{MgCO}_3(\text{s})$

**A14.**

The floc forms as a jelly-like precipitate in the water. Impurities are trapped in the floc and removed when the water is run off.

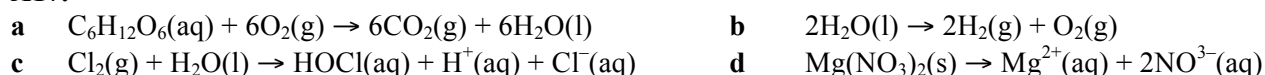
**A15.**

- a** Least scum would form in the Melbourne water as it has the lowest total concentration of calcium, magnesium and iron(III) ions.  
**b** Most scum would form in the Brisbane water as it has the highest total concentration of calcium, magnesium and iron(III) ions.

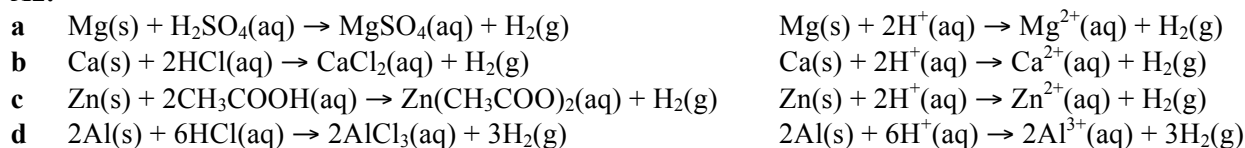
**A16.**

- a** Distillation involves boiling the impure water and collecting and condensing the pure water vapour. The dissolved impurities remain in the original flask. De-ionisation involves passing the impure water over a resin that has the ability to adsorb ions onto its surface, releasing  $\text{H}^{+}$  and  $\text{OH}^{-}$  ions. These react to form water.

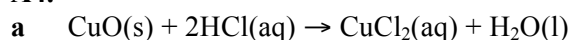
**b, c** Individual student responses required.

**A17.****Chapter 13 Introducing acids and bases****Chapter review****A1.**

Various answers involving a selection of acids such as  $\text{H}_2\text{SO}_4$ ,  $\text{HCl}$ ,  $\text{HNO}_3$ ,  $\text{CH}_3\text{COOH}$ ,  $\text{HF}$  or  $\text{H}_3\text{PO}_4$ .

**A2.****A3.**

- a** magnesium sulfate      **b** calcium chloride      **c** zinc acetate      **d** aluminium chloride

**A4.**

- b**  $2\text{LiOH}(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{Li}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$   
**c**  $\text{Na}_2\text{CO}_3(\text{s}) + 2\text{HNO}_3(\text{aq}) \rightarrow 2\text{NaNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$   
**d**  $\text{H}_2\text{SO}_4(\text{aq}) + \text{MgCO}_3(\text{s}) \rightarrow \text{MgSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$   
**e**  $\text{Ca}(\text{OH})_2(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$   
**f**  $\text{HNO}_3(\text{aq}) + \text{NaHCO}_3(\text{s}) \rightarrow \text{NaNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$

**A5.**

- i** **a**  $\text{ZnO}(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{ZnSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
**b**  $\text{Ca}(\text{s}) + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Ca}(\text{NO}_3)_2(\text{aq}) + \text{H}_2(\text{g})$   
**c**  $\text{Cu}(\text{OH})_2(\text{s}) + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Cu}(\text{NO}_3)_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$   
**d**  $3\text{FeO}(\text{s}) + 2\text{H}_3\text{PO}_4(\text{aq}) \rightarrow \text{Fe}_3(\text{PO}_4)_2(\text{s}) + 3\text{H}_2\text{O}(\text{l})$   
**e**  $\text{Mg}(\text{HCO}_3)_2(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l}) + 2\text{CO}_2(\text{g})$   
**f**  $\text{SnCO}_3(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{SnSO}_4(\text{s}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$   
**ii** **a**  $\text{ZnO}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
**b**  $\text{Ca}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + \text{H}_2(\text{g})$   
**c**  $\text{Cu}(\text{OH})_2(\text{s}) + \text{H}^+(\text{aq}) \rightarrow \text{Cu}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
**d**  $3\text{FeO}(\text{s}) + 6\text{H}^+(\text{aq}) + 2\text{PO}_4^{3-}(\text{aq}) \rightarrow \text{Fe}_3(\text{PO}_4)_2(\text{s}) + 3\text{H}_2\text{O}(\text{l})$   
**e**  $\text{Mg}(\text{HCO}_3)_2(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
**f**  $\text{SnCO}_3(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Sn}^{2+}(\text{s}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$

**A6.**

- a**  $\text{HNO}_3(\text{aq}) + \text{KOH}(\text{aq}) \rightarrow \text{KNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
**b**  $\text{H}_2\text{SO}_4(\text{aq}) + \text{K}_2\text{CO}_3(\text{aq}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$   
**c**  $2\text{HCl}(\text{aq}) + \text{CuO}(\text{s}) \rightarrow \text{CuCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{g})$   
**d**  $2\text{HNO}_3(\text{aq}) + \text{CaO}(\text{s}) \rightarrow \text{Ca}(\text{NO}_3)_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$   
**e**  $2\text{H}_3\text{PO}_4(\text{aq}) + 3\text{Ca}(\text{HCO}_3)_2(\text{s}) \rightarrow \text{Ca}_3(\text{PO}_4)_2(\text{s}) + 6\text{H}_2\text{O}(\text{l}) + 6\text{CO}_2(\text{g})$   
**f**  $2\text{HF}(\text{aq}) + \text{Zn}(\text{OH})_2(\text{s}) \rightarrow \text{ZnF}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$

**A7.**

The first step, as in the development of any equation, is to write the correct chemical formulas for each of the chemicals involved.

- a**  $\text{Fe}_2\text{O}_3(\text{s}) + 6\text{HCl}(\text{aq}) \rightarrow 2\text{FeCl}_3(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$   
**b**  $\text{Ca}(\text{OH})_2(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{CaSO}_4(\text{s}) + 2\text{H}_2\text{O}(\text{l})$   
**c**  $\text{CaCO}_3(\text{s}) + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Ca}(\text{NO}_3)_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$

**A8.**

The first step, as in the development of any equation, is to write the correct chemical formulas for each of the chemicals involved.

- |   |  |
|---|--|
| <b>a</b> $2\text{KOH}(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O}(\text{l})$                             | $\text{OH}^-(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$                            |
| <b>b</b> $\text{NaOH}(\text{aq}) + \text{HNO}_3(\text{aq}) \rightarrow \text{NaNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$   | $\text{OH}^-(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l})$                            |
| <b>c</b> $\text{MgO}(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$  | $\text{MgO}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$ |
| <b>d</b> $\text{CuO}(\text{s}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{CuSO}_4(\text{aq}) + \text{H}_2\text{O}(\text{l})$  | $\text{CuO}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Cu}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l})$ |
| <b>e</b> $\text{KHCO}_3(\text{s}) + \text{HF}(\text{aq}) \rightarrow \text{KF}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$                             | $\text{HCO}_3^-(\text{s}) + \text{H}^+(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$  |
| <b>f</b> $\text{Zn}(\text{s}) + 2\text{HNO}_3(\text{aq}) \rightarrow \text{Zn}(\text{NO}_3)_2(\text{aq}) + \text{H}_2(\text{g})$  | $\text{Zn}(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + \text{H}_2(\text{g})$          |
| <b>g</b> $\text{CaCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$                       |  |
| $\text{CaCO}_3(\text{s}) + 2\text{H}^+(\text{aq}) \rightarrow \text{Ca}^{2+}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$                               |  |
| <b>h</b> $\text{NaHCO}_3(\text{s}) + \text{CH}_3\text{COOH}(\text{aq}) \rightarrow \text{CH}_3\text{COONa}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$ |  |
| $\text{NaHCO}_3(\text{s}) + \text{H}^+(\text{aq}) \rightarrow \text{Na}^+(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$                                  |  |

**A9.**

- a** Common acids used in the home include ethanoic acid (in vinegar) and tartaric acid (used in cooking) or ascorbic acid (in vitamin C tablets). Common bases include sodium hydroxide (in oven cleaner) and sodium bicarbonate (an ingredient in some antacid tablets and used as a raising agent in cooking).  
**b** **i**  $\text{NaHCO}_3(\text{s}) + \text{CH}_3\text{COOH}(\text{aq}) \rightarrow \text{CH}_3\text{COONa}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$   
**ii**  $\text{CH}_3\text{COOH}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{CH}_3\text{COONa}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$   
**iii**  $2\text{NaHCO}_3(\text{aq}) + \text{HOOCCH}(\text{OH})\text{CH}(\text{OH})\text{COOH}(\text{aq}) \rightarrow$



- c Avoid contact with skin and eyes. Wear gloves. Wash from skin if contact occurs. If accidentally swallowed, seek medical attention.

**A10.**

- a Balancing overall equations requires establishing a correct formula for all reactants and products, then placing coefficients in front of each to ensure that the total number of all reactant atoms equals the total number of product atoms. All equations must include states. The arrow represents a change in time, but makes no indication of the rate of reaction.
- b Ionic equations take the overall equation and eliminate any species that remain unchanged. The most common species removed in this way are spectator ions which, by definition, are not involved in the reaction.
- c The inclusion of states helps describe the chemical changes involved. Those species remaining unchanged in state or formula may be considered not to react.
- d Overall equations account for all atoms or ions and the changes that occur when the reaction occurs. As well as identifying those species that change, overall equations can also identify spectator species.
- e Ionic equations identify more clearly what species are involved in chemical change, by eliminating any species that remain unchanged. Ionic equations are sometimes described as a case of 'less is more', since they focus on reacting species only.

**Chapter 14 Acids and bases****A1.**

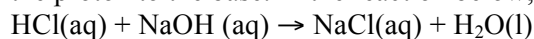
- a  $\text{Cl}^-$       b  $\text{HSO}_4^-$       c  $\text{PO}_4^{2-}$       d  $\text{CO}_3^{2-}$       e  $\text{NO}_3^-$

**A2.**

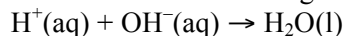
- a  $\text{NH}_4^+$       b  $\text{CH}_3\text{COO}^-$       c  $\text{H}_2\text{PO}_4^{2-}$       d  $\text{HCO}_3^-$       e  $\text{OH}^-$

**A3.**

Brønsted–Lowry acid–base reactions are those involving the exchange of a proton ( $\text{H}^+$  ion). The acid donates the proton to the base. In the reaction below, the HCl loses a proton to the base.



The ionic equation provides a clearer way (by eliminating spectator ions) of noting the reaction between the  $\text{H}^+$  and  $\text{OH}^-$  ions neutralising to form water.

**A4.**

- (1)  $\text{H}_2\text{PO}_4^-(\text{aq})$       (2)  $\text{HPO}_4^{2-}(\text{aq})$       (3)  $\text{H}_2\text{O(l)}$  (although  $\text{H}_3\text{O}^+$  is not shown here)

**A5.**

As an acid, the reactant donates one proton:

- a  $\text{HCO}_3^- + \text{H}_2\text{O(l)} \rightarrow \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$   
 b  $\text{HPO}_4^{2-} + \text{H}_2\text{O(l)} \rightarrow \text{PO}_4^{3-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$   
 c  $\text{HSO}_4^- + \text{H}_2\text{O(l)} \rightarrow \text{SO}_4^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$   
 d  $\text{H}_2\text{O} + \text{H}_2\text{O(l)} \rightarrow \text{OH}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$

As a base, the reactants accept one proton

- a  $\text{HCO}_3^- + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{CO}_3^-(\text{aq}) + \text{OH}^-(\text{aq})$   
 b  $\text{HPO}_4^{2-} + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{PO}_4^-(\text{aq}) + \text{OH}^-(\text{aq})$   
 c  $\text{HSO}_4^- + \text{H}_2\text{O(l)} \rightarrow \text{H}_2\text{SO}_4^-(\text{aq}) + \text{OH}^-(\text{aq})$   
 d  $\text{H}_2\text{O} + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{OH}^-(\text{aq})$

**A6.**

- a  $\text{HClO}_4(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{ClO}_4^-(\text{aq})$       b  $\text{HCN(aq)} + \text{H}_2\text{O(l)} \rightleftharpoons \text{H}_3\text{O}^+(\text{aq}) + \text{CN}^-(\text{aq})$   
 c  $\text{NH}_3(\text{aq}) + \text{H}_2\text{O(l)} \rightleftharpoons \text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq})$

**A7.**

- (1)  $\text{H}_3\text{AsO}_4(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{H}_2\text{AsO}_4^-(\text{aq})$       (2)  $\text{H}_2\text{AsO}_4^-(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{HAsO}_4^{2-}(\text{aq})$   
 (3)  $\text{HAsO}_4^{2-}(\text{aq}) + \text{H}_2\text{O(l)} \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{AsO}_4^{3-}(\text{aq})$

**A8.**

The concentration is measured in Molar ( $M$ ), with less than 1  $M$  considered to be dilute and 6  $M$  would be deemed to be concentrated. Nitric and hydrochloric acids are strong acids, whereas ethanoic and carbonic acids are weak.

- a 0.1  $M$  nitric acid      b 6  $M$  hydrochloric acid      c 0.1  $M$  carbonic acid  
 d 6  $M$  ethanoic acid

**A9.**

At 25°C,  $[\text{OH}^-] \times [\text{H}_3\text{O}^+] = 1 \times 10^{-14} \text{ M}$  (Note: [ ] denotes concentration in Molar units.)

- a**  $10^{-11} \text{ M}$       **b**  $10^{-9} \text{ M}$       **c**  $1.8 \times 10^{-6} \text{ M}$       **d**  $2.9 \times 10^{-3} \text{ M}$   
**e**  $1.5 \times 10^{-13} \text{ M}$       **f**  $4.5 \times 10^{-2} \text{ M}$

**A10.**

At 25°C,  $[\text{OH}^-] \times [\text{H}_3\text{O}^+] = 1 \times 10^{-14} \text{ M}$  so  $[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14} \text{ M}}{[\text{OH}^-]}$

- a**  $10^{-8} \text{ M}$       **b**  $10^{-12} \text{ M}$       **c**  $10^{-10} \text{ M}$       **d**  $3.5 \times 10^{-10} \text{ M}$   
**e**  $1.4 \times 10^{-12} \text{ M}$       **f**  $1.1 \times 10^{-5} \text{ M}$

**A11.**

- a**  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+] = -\log_{10}(0.1) = 1$       **b** 3      **c** 2      **d** 7

Then the pH is calculated using the formula  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$

- e**  $[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14} \text{ M}}{[\text{OH}^-]} = \frac{1 \times 10^{-14} \text{ M}}{0.1} = 1 \times 10^{-13} \text{ M}$  then  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+] = -\log_{10}(1 \times 10^{-13} \text{ M}) = 13$

- f** 11      **g** 4      **h** 7

**A12.**

- i a** If  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$  then  $[\text{H}_3\text{O}^+] = 10^{-\text{pH}}$  (or ten to the power of pH)  $= 10^{-1} = 0.1 \text{ M}$

- b**  $10^{-3} \text{ M}$       **c**  $10^{-7} \text{ M}$       **d**  $2 \times 10^{-12} \text{ M}$

- ii a** At 25°C,  $[\text{OH}^-] \times [\text{H}_3\text{O}^+] = 1 \times 10^{-14} \text{ M}$  so  $[\text{OH}^-] = \frac{1 \times 10^{-14} \text{ M}}{[\text{H}_3\text{O}^+]} = \frac{1 \times 10^{-14} \text{ M}}{0.1} = 10^{-13} \text{ M}$

- b**  $10^{-11} \text{ M}$       **c**  $10^{-7} \text{ M}$       **d**  $5 \times 10^{-3} \text{ M}$

**A13.**

- i a** The concentration of  $\text{H}_3\text{O}^+$  ions equals the concentration of a monoprotic acid  $= 0.0010 \text{ M} = 10^{-3} \text{ M}$ .

- b**  $[\text{OH}^-] = \frac{1 \times 10^{-14} \text{ M}}{[\text{H}_3\text{O}^+]} = \frac{1 \times 10^{-14} \text{ M}}{0.0010 \text{ M}} = 1 \times 10^{-11} \text{ M}$       **c**  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+] = -\log(10^{-3} \text{ M}) = 3$

- ii a**  $[\text{H}_3\text{O}^+] = 0.030 \text{ M}$

- b**  $[\text{OH}^-] = \frac{1 \times 10^{-14} \text{ M}}{[\text{H}_3\text{O}^+]} = \frac{1 \times 10^{-14} \text{ M}}{0.030 \text{ M}} = 3.33 \times 10^{-13} \text{ M}$       **c**  $\text{pH} = -\log(0.030 \text{ M}) = 1.52$

- iii b** Part **b** needs to be completed before part **a**.

- a**  $[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14} \text{ M}}{10^{-2} \text{ M}} = 10^{-12} \text{ M}$

$$[\text{OH}^-] = 0.010 \text{ M}$$

- c**  $\text{pH} = -\log_{10}(10^{-12} \text{ M}) = 12$

- iv a**  $10^{-4.5} \text{ M HCl} = [\text{H}_3\text{O}^+] = 3.16 \times 10^{-5} \text{ M}$

- b**  $[\text{OH}^-] = \frac{1 \times 10^{-14} \text{ M}}{[\text{H}_3\text{O}^+]} = \frac{1 \times 10^{-14} \text{ M}}{3.16 \times 10^{-5} \text{ M}} = 3.16 \times 10^{-10} \text{ M}$       **c**  $\text{pH} = -\log_{10}(3.16 \times 10^{-5} \text{ M}) = 4.5$

- v** Part **b** needs to be completed before part **a**.

- b**  $[\text{OH}^-] = 2 \times [\text{Ba}(\text{OH})_2] = 2 \times 0.0050 \text{ M} = 0.010 \text{ M}$ .

- a**  $[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14} \text{ M}}{[\text{OH}^-]} = \frac{1 \times 10^{-14} \text{ M}}{10^{-2} \text{ M}} = 1 \times 10^{-12} \text{ M}$       **c**  $\text{pH} = -\log_{10}(1 \times 10^{-2} \text{ M}) = 12$

- vi a**  $n(\text{HCl}) = \frac{\text{mass}}{\text{Molar mass}} = \frac{0.35 \text{ g}}{36.5} = 0.0096 \text{ mol}$  then  $[\text{H}_3\text{O}^+] = [\text{HCl}] = \frac{n}{V} = \frac{0.0096}{0.20 \text{ L}} = 0.48 \text{ M}$

- b**  $[\text{OH}^-] = \frac{1 \times 10^{-14} \text{ M}}{[\text{H}_3\text{O}^+]} = \frac{1 \times 10^{-14} \text{ M}}{0.48 \text{ M}} = 2.08 \times 10^{-14} \text{ M}$       **c**  $\text{pH} = -\log_{10}(0.48 \text{ M}) = 0.32$

- vii** Part **b** needs to be completed before part **a**.

- b**  $n(\text{KOH}) = \frac{\text{mass}}{\text{Molar mass}} = \frac{0.50 \text{ g}}{56.1} = 0.00891 \text{ mol}$  so  $[\text{KOH}] = \frac{n}{V} = \frac{0.00891}{0.50 \text{ L}} = 0.0178 \text{ M}$

- a**  $[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14} \text{ M}}{[\text{OH}^-]} = \frac{1 \times 10^{-14} \text{ M}}{0.0178 \text{ M}} = 5.6 \times 10^{-13} \text{ M}$       **c**  $\text{pH} = -\log_{10}(0.0178 \text{ M}) = 1.75$

**A14.**

Dilution questions are best answered using the formula  $c_1V_1 = c_2V_2$ , where  $c$  is the concentration in mol/L and  $V$

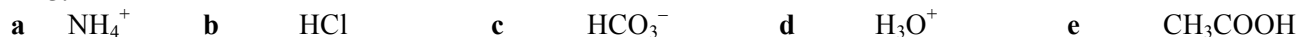
is the volume of the solution. Each of the volume units needs to be the same, although not necessarily litres.

**a**  $c(\text{HCl}) = \frac{0.20 \times 10}{20} = 0.10 \text{ M}$  so the  $\text{pH} = -\log_{10}(0.10 \text{ M}) = 1$

**b**  $c(\text{NaOH}) = \frac{0.10 \times 10}{100} = 0.010 \text{ M}$  so the  $[\text{H}_3\text{O}^+] = 10^{-12}$  and therefore the  $\text{pH} = 12$

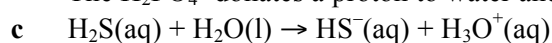
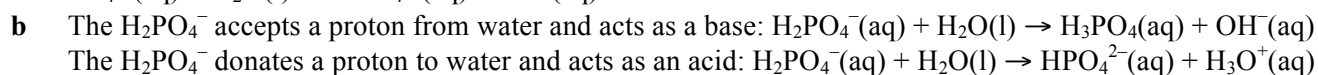
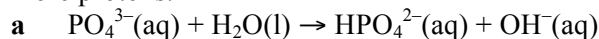
## Chapter review

**A15.**



**A16.**

Remember that if a chemical acts as a base, it will accept a proton. In this question, the proton comes from a water molecule, but this is not always the case. If a chemical acts as an acid, it must be able to donate one or more protons.

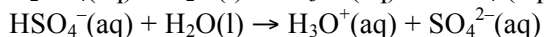
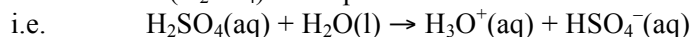


**A17.**

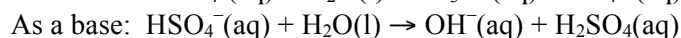
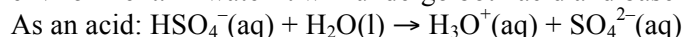


**A18.**

**a** Sulfuric acid ( $\text{H}_2\text{SO}_4$ ) is a diprotic acid because each molecule can donate two protons to a base



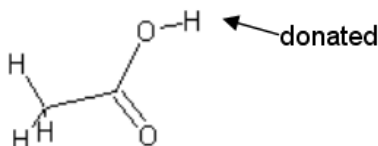
The  $\text{HSO}_4^-$  ion, however, is amphiprotic because it can act as either an acid or a base, depending on the environment. In water it will undergo both acid and base reactions. For example,



**b** A strong acid is one which ionises completely in solution (e.g.  $\text{HCl}$ ). A concentrated acid is one in which there is a large amount of acid dissolved in a given volume of solution; for example, 5 M  $\text{HCl}$  and 5 M  $\text{CH}_3\text{COOH}$  are concentrated acids.

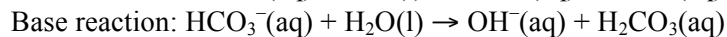
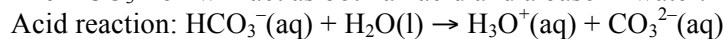
**A19.**

Include a diagram such as:



**A20.**

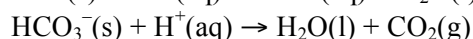
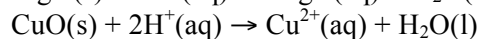
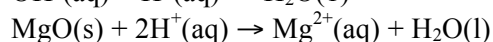
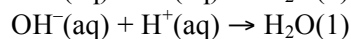
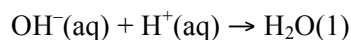
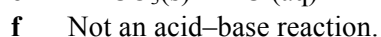
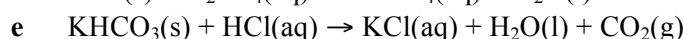
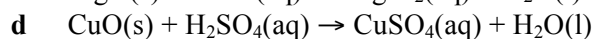
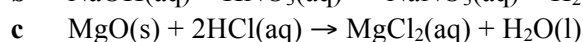
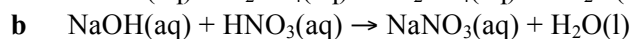
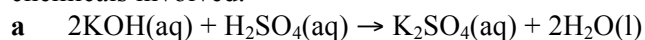
The  $\text{HCO}_3^-$  ion will act as both an acid and a base in water:



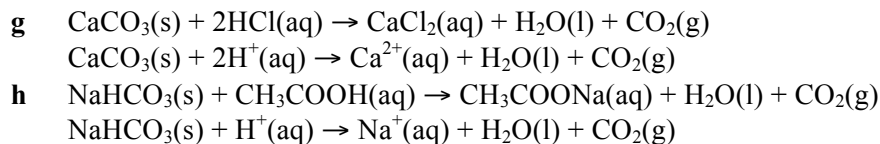
Although both reactions occur, because the measured pH of the solution is greater than 7, we can assume that at any one time more ions are acting as a base than as an acid.

**A21.**

The first step, as in the development of any equation, is to write the correct chemical formulas for each of the chemicals involved.







A22.

b,  $\text{HPO}_4^{2-}$  is amphoteric, since it can donate a proton to become  $\text{PO}_4^{3-}$  or accept a proton to form  $\text{H}_2\text{PO}_4^-$ .

A23.

A solution with a pH of 7.4 is basic so you need to use  $[\text{H}_3\text{O}^+] \times [\text{OH}^-] = 10^{-14}$  at  $25^\circ\text{C}$  and  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$ . The assumption made is that at body temperature (approximately  $38^\circ\text{C}$ ), the ionisation of water is not significantly different from that at  $25^\circ\text{C}$ .

A24.

Remember to use  $[\text{H}_3\text{O}^+] \times [\text{OH}^-] = 10^{-14}$  at  $25^\circ\text{C}$  and  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$ .

- a  $\text{pH} = 2$  so  $\therefore [\text{H}_3\text{O}^+] = 10^{-2}$  or  $0.01 \text{ M}$   
b The formula for amounts of substance in solution is  $n = c \times V$  (where  $n$  is the amount in mole,  $c$  the concentration in mol/L and  $V$  the volume of the solution in litres).  $n = 0.01 \times 0.500 = 0.005 \text{ mol}$

A25.

Remember:  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$ .

$\text{pH} = 3$  so  $[\text{H}_3\text{O}^+] = 10^{-3} \text{ M}$        $\text{pH} = 5$  so  $[\text{H}_3\text{O}^+] = 10^{-5} \text{ M}$        $\therefore$  the difference is a factor of 100.

A26.

- a  $\text{pH} = -\log_{10}(0.001 \text{ M}) = 3$       b 5      c 8.2      d 11.5  
e 1.2      f 12.7

A27.

- a  $[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14} \text{ M}}{[\text{OH}^-]} = \frac{1 \times 10^{-14} \text{ M}}{0.000001 \text{ M}} = 1.0 \times 10^{-8} \text{ M}$  so the  $\text{pH} = -\log_{10}(1.0 \times 10^{-8} \text{ M}) = 8$   
b 12      c 10      d 9.45      e 11.9      f 4.97

A28.

- a  $[\text{H}^+] = 10^{-\text{pH}} = 10^{-3}$  or  $0.001 \text{ M}$  so the  $[\text{OH}^-] = \frac{1 \times 10^{-14} \text{ M}}{[\text{H}^+]} = \frac{1 \times 10^{-14} \text{ M}}{0.001 \text{ M}} = 1.0 \times 10^{-11} \text{ M}$   
b  $10^{-10} \text{ M H}^+$ ,  $10^{-4} \text{ M OH}^-$       c  $3.16 \times 10^{-9} \text{ M H}^+$ ,  $3.16 \times 10^{-6} \text{ M OH}^-$   
d  $1.58 \times 10^{-6} \text{ M H}^+$ ,  $6.3 \times 10^{-9} \text{ M OH}^-$       e  $2.5 \times 10^{-10} \text{ M H}^+$ ,  $4.0 \times 10^{-5} \text{ M OH}^-$   
f  $3.16 \times 10^{-14} \text{ M H}^+$ ,  $0.316 \text{ M OH}^-$

A29.

pH	$[\text{H}^+]$	$[\text{OH}^-]$
1.0	$1.0 \times 10^{-1} \text{ M}$	$1.0 \times 10^{-13} \text{ M}$
2.6	$2.51 \times 10^{-3} \text{ M}$	$4.0 \times 10^{-12} \text{ M}$
5.5	$3.16 \times 10^{-6} \text{ M}$	$3.16 \times 10^{-9} \text{ M}$
3	$1.0 \times 10^{-3} \text{ M}$	$1.0 \times 10^{-11} \text{ M}$
9	$1.0 \times 10^{-9} \text{ M}$	$1.0 \times 10^{-5} \text{ M}$
8.6	$2.56 \times 10^{-9} \text{ M}$	$3.9 \times 10^{-6} \text{ M}$
3.72	$1.88 \times 10^{-4} \text{ M}$	$5.32 \times 10^{-11} \text{ M}$
13.7	$1.8 \times 10^{-14} \text{ M}$	$5.7 \times 10^{-1} \text{ M}$
8.5	$3.16 \times 10^{-9} \text{ M}$	$3.16 \times 10^{-6} \text{ M}$
6.1	$7.7 \times 10^{-7} \text{ M}$	$1.29 \times 10^{-8} \text{ M}$
9.4	$3.8 \times 10^{-10} \text{ M}$	$2.8 \times 10^{-5} \text{ M}$

A30.

Remember:  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$  and  $[\text{H}_3\text{O}^+] \times [\text{OH}^-] = 10^{-14}$  at  $25^\circ\text{C}$ . Assume that the temperature is  $25^\circ\text{C}$ , and that each of the chemicals dissociates completely.

- i  $0.10 \text{ M HCl}$       a  $[\text{H}_3\text{O}^+] = 10^{-1} \text{ M}$       b  $[\text{OH}^-] = 10^{-13}$       c  $\text{pH} = 1$

- ii** 0.10 M HCl      **a**  $[\text{H}_3\text{O}^+] = 10^{-1} \text{ M}$       **b**  $[\text{OH}^-] = 10^{-13}$       **c** pH = 1  
**iii** 0.1 M NaOH      **a**  $[\text{H}_3\text{O}^+] = 10^{-13} \text{ M}$       **b**  $[\text{OH}^-] = 10^{-1} \text{ M}$       **c** pH = 13  
**iv** 0.10 M NaOH      **a**  $[\text{H}_3\text{O}^+] = 10^{-13} \text{ M}$       **b**  $[\text{OH}^-] = 10^{-1} \text{ M}$       **c** pH = 13  
**v** 0.0010 M  $\text{HNO}_3$       **a**  $[\text{H}_3\text{O}^+] = 10^{-3} \text{ M}$       **b**  $[\text{OH}^-] = 10^{-11} \text{ M}$       **c** pH = 3  
**vi** 0.0016 M KOH      **a**  $[\text{H}_3\text{O}^+] = 6.25 \times 10^{-12} \text{ M}$       **b**  $[\text{OH}^-] = 1.6 \times 10^{-3}$       **c** pH = 11.2  
**vii**  $1.5 \times 10^{-5} \text{ M HCl}$       **a**  $[\text{H}_3\text{O}^+] = 1.5 \times 10^{-5} \text{ M}$       **b**  $[\text{OH}^-] = 6.7 \times 10^{-10}$       **c** pH = 4.8  
**viii** 0.005 M  $\text{Ca(OH)}_2$        $n(\text{OH}^-) = 2 \times 0.0135 = 0.0270 \text{ mol}$       **b**  $[\text{OH}^-] = \frac{0.0270 \text{ mol}}{0.400 \text{ L}} = 0.0675 \text{ M}$   
**a**  $[\text{H}_3\text{O}^+] = 1.48 \times 10^{-13} \text{ M}$       **c** pH = 12.8

**A31.**

- a**  $\text{H}_2\text{SO}_4$  is a strong diprotic acid, whereas HCl is a strong monoprotic acid. The 0.1 M HCl ionises completely in solution, giving a pH of 1. The first ionisation stage of the  $\text{H}_2\text{SO}_4$  is complete and the second stage is partial. Overall, the concentration of  $\text{H}_3\text{O}^+$  ions in the  $\text{H}_2\text{SO}_4$  is greater than in HCl of equal molarity. Therefore, the  $\text{H}_2\text{SO}_4$  has a lower pH.  
**b** Both acids are listed as having identical concentrations. Hydrochloric acid is a strong acid and is said to ionise completely in solution. Ethanoic acid is an example of a weak acid, and only partially ionises in solution. Therefore, HCl produces a much greater concentration of  $\text{H}^+$  ions and will result in a lower pH.  
**c** Acetic acid is neutralised as the  $\text{OH}^-$  is added; this removal of  $\text{H}^+(\text{aq})$  ions from solution leads to an increase in pH. After all the acetic acid has been neutralised, the pH continues to rise as  $[\text{OH}^-]$  increases.

**A32.**

When carbon dioxide is bubbled through water, it partially dissolves to produce a weak acidic solution, according to the equation below.  $\text{CO}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{H}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$ , Acids have a sour taste, and a pH of less than 7.

**A33.**

These three questions have two steps.

Step 1 Dilution questions are best answered using the formula  $c_1V_1 = c_2V_2$ , where  $c$  is the concentration in mol/L and  $V$  is the volume of the solution. Each of the volume units needs to be the same, although not necessarily litres.

Step 2 Also remember,  $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+]$ .

- a**  $c_2 = 0.025 \times \frac{10}{50} = 0.005 \text{ M}$  so  $[\text{H}_3\text{O}^+] = 0.005 \text{ M}$  and  $\text{pH} = -\log_{10}(0.005 \text{ M}) = 2.3$   
**b**  $c_2 = 0.0050 \times \frac{20}{500} = 2.0 \times 10^{-4} \text{ M}$  so  $[\text{OH}^-] = 2.0 \times 10^{-4} \text{ M}$ .  

$$[\text{H}_3\text{O}^+] = \frac{1 \times 10^{-14} \text{ M}}{[\text{OH}^-]} = \frac{1 \times 10^{-14} \text{ M}}{2 \times 10^{-4} \text{ M}} = 5.0 \times 10^{-11} \text{ M}$$
 and  $\text{pH} = -\log_{10}(5.0 \times 10^{-11} \text{ M}) = 10.3$   
**c**  $c_2 = 0.15 \times \frac{10}{1500}$  (1.5 L has been converted to mL to maintain identical units) = 0.001 M  
 $[\text{H}_3\text{O}^+] = 0.001 \text{ M} = 10^{-3} \text{ M}$  and  $\text{pH} = 3$

**A34.**

Solution A: weaker base, few freely moving charged particles—ammonia

Solution B: neutral, no freely moving charged particles—glucose

Solution C: strong base, many freely moving charged particles—sodium hydroxide

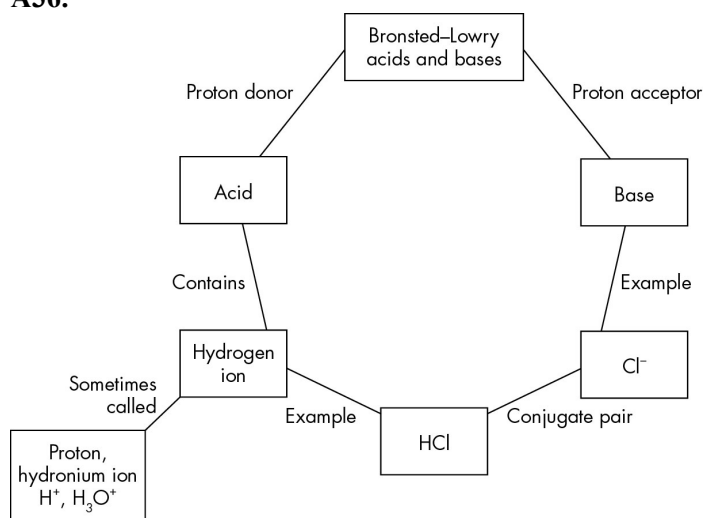
Solution D: strong acid, many freely moving charged particles—hydrochloric acid

Solution E: weaker acid, few freely moving charged particles—ethanoic acid

**A35.**

- a** **i** A Brønsted–Lowry acid is a proton donor.  
**ii** A strong base is a substance that ionises completely in water.  
**iii** Molarity is a measure of concentration of a solution expressed in  $\text{mol L}^{-1}$ .  
**iv** The conjugate acid of a base contains one more hydrogen ion (proton) than the base.  
**b** An amphiprotic substance can act as an acid (proton donor) or a base (proton acceptor).  
 Acting as an acid:  $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{CO}_3^{2-}(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$   
 Acting as a base:  $\text{HCO}_3^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{CO}_3(\text{aq}) + \text{OH}^-(\text{aq})$

A36.



## Chapter 15 Calculations in chemistry: stoichiometry

A1.

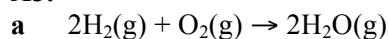
The balanced equation shows that 1 mol of iron produces 1 mol of copper. The amount of each is found by using  $n = \frac{m}{M}$ , where  $m$  is the mass in grams, and  $M$  is the molar mass. A periodic table is used to calculate the molar masses of Fe = 55.8 g mol<sup>-1</sup> and Cu = 63.5 g mol<sup>-1</sup>.

$$\frac{n(\text{Cu})}{n(\text{Fe})} = \frac{1}{1} \text{ so } n(\text{Cu}) = n(\text{Fe}) = \frac{1000}{55.8} = 17.9 \text{ mol and } m(\text{Cu}) = 17.9 \times 63.5 = 1138 \text{ g} = 1.1 \text{ kg}$$

A2.

$$\frac{n(\text{Fe})}{n(\text{Zn})} = \frac{2}{3} \text{ so } n(\text{Fe}) = \frac{2}{3} \times n(\text{Zn}) = \frac{2}{3} \times \frac{25.0}{65.4} = 0.255 \text{ mol and } m(\text{Fe}) = 0.255 \times 55.8 = 14.2 \text{ g}$$

A3.



b  $\frac{n(\text{O}_2)}{n(\text{H}_2)} = \frac{1}{2} \text{ so } n(\text{O}_2) = \frac{n(\text{H}_2)}{2} = \frac{10}{2} \times \frac{1}{2} = 2.5 \text{ mol and } m(\text{O}_2) = 2.5 \times 32.0 = 80 \text{ g}$

A4.

a  $m(\text{O}_2) = 21.9 \times 32.0 = 701.8 \text{ g}$

b  $m(\text{CO}_2) = 14 \times 44.0 = 616 \text{ g}$

A5.

$m(\text{KClO}_4) = 0.159 \times 138.6 = 22.0 \text{ g}$

$m(\text{KCl}) = 0.0530 \times 74.6 = 4.0 \text{ g}$

A6.

$V(\text{H}_2\text{SO}_4) = \frac{0.169}{0.250} = 0.675 \text{ L} = 675 \text{ mL}$

A7.

a  $c(\text{NaCl}) = \frac{0.210}{0.025} = 8.4 \text{ M}$

b  $m(\text{AgCl}) = 0.0210 \times 143.4 = 3.01 \text{ g}$

A8.

a  $\text{BaCl}_2(\text{aq}) + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{BaSO}_4(\text{s}) + 2\text{HCl}(\text{aq})$       b  $c(\text{H}_2\text{SO}_4) = \frac{0.00555}{0.024} = 0.231 \text{ M}$

A9.

a Magnesium sulfate is in excess by  $(2.0 - 1.0) = 1.0 \text{ mol}$

b Magnesium sulfate is in excess by  $(2.0 - 0.50) = 1.5 \text{ mol}$

c Lead nitrate is in excess by  $(3.0 - 0.20) = 2.8 \text{ mol}$

**A10.**

$$\text{a} \quad n(\text{Ca}) = \frac{30.0}{40.0} = 0.750 \text{ mol} \qquad n(\text{H}_2\text{O}) = \frac{30.0}{18.0} = 1.67 \text{ mol}$$

$$\text{b} \quad n(\text{H}_2\text{O}) \text{ required} = \frac{2}{1} \times n(\text{Ca}) = 1.500 \text{ mol but } n(\text{H}_2\text{O}) \text{ available} = 1.67 \text{ mol}$$

So, all Ca will be used and is therefore the limiting reagent.  $\text{H}_2\text{O}$  is in excess by  $1.67 - 1.50 = 0.17 \text{ mol}$

$$\text{c} \quad n(\text{Ca}(\text{OH})_2) = n(\text{Ca}) = 0.750 \text{ mol and } m(\text{Ca}(\text{OH})_2) = 0.750 \times 74.1 = 55.4 \text{ g}$$

**A11.**

**a** The balanced equation shows that 1 mol of phosphoric acid reacts with 3 mol of potassium hydroxide. The amount of each is found using  $n = cV$ , where  $c$  is the concentration in  $\text{mol L}^{-1}$ , and  $V$  is the volume in litres.

$$n(\text{KOH}) = 1.00 \times 0.0100 = 0.0100 \text{ mol and } n(\text{H}_3\text{PO}_4) = 2.0 \times 0.0325 = 0.0650 \text{ mol}$$

$$n(\text{H}_3\text{PO}_4) \text{ required} = \frac{1}{3} \times n(\text{KOH}) = \frac{1}{3} \times 0.100 = 0.0333 \text{ mol but } n(\text{H}_3\text{PO}_4) \text{ available} = 0.0650 \text{ mol}$$

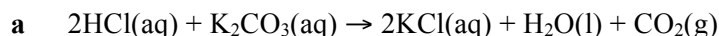
So, all KOH will be used and is the limiting reagent.  $\text{H}_3\text{PO}_4$  is in excess by  $0.0650 - 0.0333 = 0.0317 \text{ mol}$

$$\text{b} \quad n(\text{K}_3\text{PO}_4) = \frac{1}{3} \times n(\text{KOH}) = \frac{1}{3} \times 0.100 = 0.0333 \text{ mol and } m(\text{K}_3\text{PO}_4) = 0.0333 \times 212.3 = 7.08 \text{ g}$$

**A12.**

$$n(\text{KOH}) = 0.09927 \times 0.0200 = 0.001985 \text{ mol and } n(\text{HNO}_3) = 0.001985 \text{ mol}$$

$$c(\text{HNO}_3) = \frac{0.001985}{0.01826} = 0.1087 \text{ mol L}^{-1}$$

**A13.**

$$\text{b} \quad n(\text{K}_2\text{CO}_3) = 0.200 \times 0.0200 = 0.00400 \text{ mol and } n(\text{HCl}) = \frac{2}{1} \times n(\text{K}_2\text{CO}_3) = 0.00800 \text{ mol}$$

$$\text{So } c(\text{HCl}) = \frac{0.00800}{0.02240} = 0.3572 \text{ mol L}^{-1}$$

**Chapter review****A14.**

$$\text{a} \quad \frac{n(\text{MgCO}_3)}{n(\text{CO}_2)} = \frac{1}{1}, n(\text{CO}_2) = \frac{10.0}{44} = 0.227 \text{ mol \& } n(\text{MgCO}_3) = 0.227 \text{ mol so } m(\text{MgCO}_3) = 0.227 \times 84.3 = 19.2 \text{ g}$$

$$\text{b} \quad \frac{n(\text{HCl})}{n(\text{CO}_2)} = \frac{2}{1}, n(\text{HCl}) = 2 \times 0.227 = 0.454 \text{ mol so } m(\text{HCl}) = 0.454 \times 36.5 = 16.6 \text{ g}$$

**A15.**

$$\text{a} \quad n(\text{Al}) = \frac{1000000}{27} = 37037 \text{ mol and } n(\text{Al}_2\text{O}_3) = \frac{2}{4} \times 37037 = 18520 \text{ mol}$$

$$\text{so } m(\text{Al}_2\text{O}_3) = 18520 \times 102 = 1889 \text{ kg}$$

$$\text{b} \quad n(\text{Al}) = \frac{1000000}{27} = 37037 \text{ mol and } n(\text{C}) = \frac{3}{4} \times 37037 = 27777.75 \text{ mol}$$

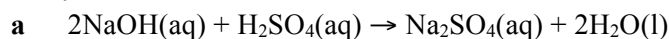
$$\text{so } m(\text{C}) = 27777.75 \times 12 = \frac{333333}{1000} = 333.3 \text{ kg}$$

$$\text{c} \quad n(\text{Al}) = \frac{1000000}{27} = 37037 \text{ mol and } n(\text{CO}_2) = \frac{3}{4} \times 37037 = 27777.75 \text{ mol}$$

$$\text{so } m(\text{CO}_2) = 27777.75 \times 44 = \frac{1222221}{1000} = 1222 \text{ kg}$$

**A16.**

$$n(\text{aspirin}) = \frac{300}{180} = 1.67 \text{ mol and } n(\text{salicylic acid}) = 1.67 \text{ mol so } m(\text{salicylic acid}) = 1.67 \times 138 = 230 \text{ g}$$

**A17.**

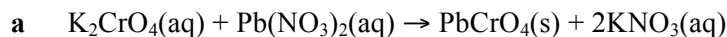
**b**  $n(\text{sulfuric acid}) = \frac{5.0}{98} = 0.051 \text{ mol}$  and  $n(\text{NaOH}) = 2 \times 0.051 \text{ mol} = 0.102 \text{ mol}$

so  $m(\text{NaOH}) = 0.102 \times 40 = 4.1 \text{ g}$

**A18.**

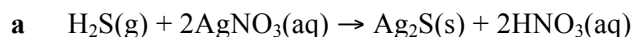
$n(\text{glucose}) = \frac{80.0}{180} = 0.444 \text{ mol}$  and  $n(\text{ethanol}) = 2 \times 0.444 \text{ mol} = 0.888 \text{ mol}$

so  $m(\text{ethanol}) = 0.888 \times 46.0 = 40.9 \text{ g}$

**A19.**

**b**  $n(\text{PbCrO}_4) = \frac{6.0}{323} = 0.0186 \text{ mol}$  and  $n(\text{K}_2\text{CrO}_4) = 0.0186 \text{ mol}$  so  $m(\text{K}_2\text{CrO}_4) = 0.0186 \times 194 = 3.6 \text{ g}$

**c** Lead pigments are toxic, particularly to small children. Because small children often chew paint on furniture, toys and other items, lead is being removed from paints.

**A20.**

**b**  $n(\text{Ag}_2\text{S}) = \frac{1.932}{248.1} = 0.007787 \text{ mol}$  and  $n(\text{AgNO}_3) = 2 \times 0.007787 \text{ mol} = 0.01557 \text{ mol}$

so  $m(\text{AgNO}_3) = 0.01557 \times 170.0 = 2.648 \text{ g}$

**A21.**

**a**  $n(\text{AgNO}_3) = \frac{2.4}{170} = 0.0141 \text{ mol}$  and  $n(\text{AgCl}) \text{ produced} = 0.0141 \text{ mol}$

so  $m(\text{AgCl}) \text{ produced} = 0.0141 \times 143.5 = 2.03 \text{ g}$

**b**  $\frac{n(\text{NaCl})}{n(\text{AgNO}_3)} = \frac{1}{1}$  and  $n(\text{AgNO}_3) = \frac{2.4}{170} = 0.0141 \text{ mol}$  and  $n(\text{NaNO}_3) \text{ produced} = 0.0141 \text{ mol}$

so  $m(\text{NaNO}_3) \text{ produced} = 0.0141 \times 85 = 1.2 \text{ g}$

**c**  $\frac{n(\text{NaCl})}{n(\text{AgNO}_3)} = \frac{1}{1}$  and  $n(\text{AgNO}_3) = \frac{2.4}{170} = 0.0141 \text{ mol}$  and  $n(\text{NaCl}) \text{ produced} = 0.0141 \text{ mol}$

so  $m(\text{NaCl}) \text{ produced} = 0.0141 \times 58.5 = 0.82 \text{ g}$

**A22.**

**a**  $n(\text{C}_3\text{H}_8) = \frac{6.70}{44} = 0.152 \text{ mol}$  and  $n(\text{CO}_2) \text{ produced} = 3 \times 0.152 \text{ mol} = 0.457 \text{ mol}$

so  $m(\text{CO}_2) \text{ produced} = 0.457 \times 44 = 20.1 \text{ g}$

**b**  $\frac{n(\text{O}_2)}{n(\text{C}_3\text{H}_8)} = \frac{5}{1}$  and  $n(\text{C}_3\text{H}_8) = \frac{6.70}{44} = 0.152 \text{ mol}$  and  $n(\text{O}_2) \text{ produced} = 5 \times 0.152 \text{ mol} = 0.76 \text{ mol}$

so  $m(\text{O}_2) \text{ produced} = 0.76 \times 32 = 24.0 \text{ g}$

**c**  $\frac{n(\text{H}_2\text{O})}{n(\text{C}_3\text{H}_8)} = \frac{4}{1}$  and  $n(\text{C}_3\text{H}_8) = \frac{6.70}{44} = 0.152 \text{ mol}$  and  $n(\text{H}_2\text{O}) \text{ produced} = 4 \times 0.152 \text{ mol} = 0.608 \text{ mol}$

so  $m(\text{H}_2\text{O}) \text{ produced} = 0.608 \times 18 = 10.8 \text{ g}$

**A23.**

**a**  $n(\text{Fe}) = \frac{85 \times 10^6}{55.8} = 1.52 \times 10^6 \text{ mol}$  and  $n(\text{CO}_2) \text{ produced} = \frac{3 \times 1.52 \times 10^6}{2} \text{ mol} = 2.28 \times 10^6 \text{ mol}$

so  $m(\text{CO}_2) \text{ produced} = 2.28 \times 10^6 \times 44 = 1.0 \times 10^8 \text{ g} = 100 \text{ tonnes}$

**b**  $n(\text{Fe}) = \frac{85 \times 10^6}{55.8} = 1.52 \times 10^6 \text{ mol}$  and  $n(\text{Fe}_2\text{O}_3) \text{ produced} = \frac{1}{2} \times 1.52 \times 10^6 \text{ mol} = 0.76 \times 10^6 \text{ mol}$

so  $m(\text{Fe}_2\text{O}_3) \text{ produced} = 0.76 \times 10^6 \times 159.6 = 121.3 \text{ tonnes}$

**c**  $n(\text{Fe}) = \frac{85 \times 10^6}{55.8} = 1.52 \times 10^6 \text{ mol}$  and  $n(\text{CO}) \text{ produced} = \frac{3}{2} \times 1.52 \times 10^6 \text{ mol} = 2\,280\,000 \text{ mol}$

so  $m(\text{CO}) \text{ produced} = 2\,280\,000 \times 28 = 64.0 \text{ tonnes}$

**A24.**

$$n(\text{NH}_3) = \frac{20 \times 10^3}{17} = 1176 \text{ mol and } n(\text{fertiliser}) = \frac{1176}{2} \text{ mol} = 588 \text{ mol}$$

However, the process is only 80% efficient.

$$n(\text{fertiliser}) = 0.80 \times 588 \text{ mol} = 471 \text{ mol so } m(\text{fertiliser}) = 471 \times 132 = 62\,000 \text{ g} = 62 \text{ kg}$$

**A25.**

- a** The balanced equation shows that 1 mol of sulfuric acid reacts with 1 mol of sodium carbonate. The amount of each is found using  $n = cV$ , where  $c$  is the concentration in  $\text{mol L}^{-1}$  and  $V$  is the volume in litres.

$$\frac{n(\text{H}_2\text{SO}_4)}{n(\text{Na}_2\text{CO}_3)} = \frac{1}{1} \text{ so } n(\text{Na}_2\text{CO}_3) = 0.200 \times 0.020 = 0.0040 \text{ mol and } n(\text{H}_2\text{SO}_4) = 0.0040 \text{ mol}$$

$$V(\text{H}_2\text{SO}_4) = \frac{0.0040}{0.250} = 16.0 \text{ mL}$$

- b**  $\frac{n(\text{Na}_2\text{CO}_3)}{n(\text{H}_2\text{SO}_4)} = \frac{1}{1}$  and  $n(\text{H}_2\text{SO}_4) = 0.520 \times 0.018\,75 = 0.009\,75 \text{ mol so } n(\text{Na}_2\text{CO}_3) = 0.009\,75 \text{ mol}$

$$c(\text{Na}_2\text{CO}_3) = \frac{0.009\,75}{0.02125} = 0.459 \text{ M}$$

**A26.**

- a** The amount of each substance is found using  $n = cV$ , where  $c$  is the concentration in  $\text{mol L}^{-1}$  and  $V$  is the volume in litres.  $\text{NaOH(aq)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$

$$\frac{n(\text{NaOH})}{n(\text{HCl})} = \frac{1}{1} \text{ so } n(\text{HCl}) = 0.200 \times 0.020 = 0.0040 \text{ mol and } n(\text{NaOH}) = 0.0040 \text{ mol}$$

$$V(\text{NaOH}) = 0.0040 / 0.10 = 0.040 \text{ L} = 40.0 \text{ mL}$$

- b**  $2\text{NaOH(aq)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{Na}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O(l)}$

$$\frac{n(\text{NaOH})}{n(\text{H}_2\text{SO}_4)} = \frac{2}{1} \text{ and } n(\text{H}_2\text{SO}_4) = 1.5 \times 0.050 = 0.075 \text{ mol so } n(\text{NaOH}) = 2 \times 0.075 \text{ mol} = 0.15 \text{ mol}$$

$$V(\text{NaOH}) = 0.15 / 0.10 = 1.5 \text{ L}$$

**A27.**

- a**  $\text{NaOH(aq)} + \text{HCl(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$

$$\frac{n(\text{KOH})}{n(\text{HCl})} = \frac{1}{1} \text{ and } n(\text{HCl}) = 2.00 \times 0.0175 = 0.035 \text{ mol so } n(\text{KOH}) = 0.035 \text{ mol}$$

$$m(\text{KOH}) = 0.035 \times 56.0 = 1.96 \text{ g}$$

- b**  $2\text{KOH(aq)} + \text{H}_2\text{SO}_4(\text{aq}) \rightarrow \text{K}_2\text{SO}_4(\text{aq}) + 2\text{H}_2\text{O(l)}$

$$\frac{n(\text{KOH})}{n(\text{H}_2\text{SO}_4)} = \frac{2}{1} \text{ and } n(\text{H}_2\text{SO}_4) = 0.126 \times 0.021\,69 = 0.002\,733 \text{ mol}$$

$$n(\text{KOH}) = 2 \times 0.002\,733 \text{ mol} = 0.005\,466 \text{ mol so } m(\text{KOH}) = 0.005\,466 \times 56.0 = 0.306 \text{ g}$$

**A28.**

- a**  $\text{CuSO}_4(\text{aq}) + \text{Zn(s)} \rightarrow \text{Cu(s)} + \text{ZnSO}_4(\text{aq})$

$$\frac{n(\text{CuSO}_4)}{n(\text{Zn})} = \frac{1}{1} \text{ and } n(\text{Zn}) = \frac{2.13}{65.4} = 0.0326 \text{ mol so } n(\text{CuSO}_4) = 0.0326 \text{ mol}$$

$$V(\text{CuSO}_4) = \frac{0.0326}{1.2} = 27.1 \text{ mL}$$

- b**  $\frac{n(\text{Cu})}{n(\text{CuSO}_4)} = \frac{1}{1}$  and  $n(\text{CuSO}_4) = 1.2 \times 0.0179 = 0.021\,48 \text{ mol so } n(\text{Cu}) = 0.021\,48 \text{ mol}$

$$m(\text{Cu}) = 0.021\,48 \times 63.5 = 1.36 \text{ g}$$

**A29.**

- a**  $\text{AgNO}_3(\text{aq}) + \text{NaCl(aq)} \rightarrow \text{AgCl(s)} + \text{NaNO}_3(\text{aq})$

- b**  $n(\text{NaCl}) = 0.171 \text{ mol so } n(\text{AgCl}) = 0.171 \text{ mol}$

$$m(\text{AgCl}) = 0.171 \times 143.5 = 24.5 \text{ g}$$

- c**  $n(\text{NaCl}) = 0.171 \text{ mol so } n(\text{AgNO}_3) = 0.171 \text{ mol}$

$$V(\text{AgNO}_3) = n / c = 122 \text{ mL}$$

**A30.**

- a**  $\frac{n(\text{Ag})}{n(\text{HNO}_3)} = \frac{1}{2}$  and  $n(\text{HNO}_3) = 0.564 \times 0.0285 = 0.0161 \text{ mol}$  so  $n(\text{Ag}) = 0.00804 \text{ mol}$   
 $m(\text{Ag}) = 0.00804 \times 108 = 0.868 \text{ g}$
- b**  $\frac{n(\text{NO}_2)}{n(\text{HNO}_3)} = \frac{1}{2}$  and  $n(\text{HNO}_3) = 2.00 \times 0.0143 = 0.0286 \text{ mol}$  so  $n(\text{NO}_2) = 0.0143 \text{ mol}$   
 $m(\text{NO}_2) = 0.0143 \times 46 = 0.658 \text{ g}$
- c**  $\frac{n(\text{HNO}_3)}{n(\text{Ag})} = \frac{2}{1}$  and  $n(\text{Ag}) = 1.1111 \text{ mol}$  so  $n(\text{HNO}_3) = 2 \times 1.1111 \text{ mol} = 2.2222 \text{ mol}$   
 $V(\text{HNO}_3) = 1.11 \text{ L}$

**A31.**

The equation for the reaction is:  $2\text{HCl}(\text{aq}) + \text{Mg}(\text{OH})_2(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l})$

- $\frac{n(\text{Mg}(\text{OH})_2)}{n(\text{HCl})} = \frac{1}{2}$  and  $n(\text{HCl}) = 0.10 \times 0.800 = 0.0800 \text{ mol}$  so  $n(\text{Mg}(\text{OH})_2) = 0.0400 \text{ mol}$   
 $m(\text{Mg}(\text{OH})_2) = 0.0400 \text{ mol} \times 58.3 \text{ g mol}^{-1} = 2.33 \text{ g}$

**A32.**

- a**  $\text{CaCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) + 2\text{NaCl}(\text{aq})$
- b**  $\frac{n(\text{Na}_2\text{CO}_3)}{n(\text{CaCl}_2)} = \frac{1}{1}$  and  $n(\text{CaCl}_2) = 0.32 \times 0.0238 = 0.00762 \text{ mol}$  so  $n(\text{Na}_2\text{CO}_3) = 0.00762 \text{ mol}$   
 $m(\text{Na}_2\text{CO}_3) = 0.00762 \times 106 = 0.807 \text{ g}$
- c**  $\frac{n(\text{CaCO}_3)}{n(\text{CaCl}_2)} = \frac{1}{1}$  and  $n(\text{CaCl}_2) = 0.32 \times 0.0238 = 0.00762 \text{ mol}$  so  $n(\text{CaCO}_3) = 0.00762 \text{ mol}$   
 $m(\text{CaCO}_3) = 0.00762 \times 100 = 0.762 \text{ g}$

**A33.**

- a**  $\text{Zn}(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g})$
- b**  $\frac{n(\text{Zn})}{n(\text{HCl})} = \frac{1}{2}$  and  $n(\text{HCl}) = 0.730 \times 0.0237 = 0.0173 \text{ mol}$  so  $n(\text{Zn}) = 0.00865 \text{ mol}$   
 $m(\text{Zn}) = 0.00865 \times 65.4 = 0.566 \text{ g}$
- c** **i**  $\frac{n(\text{H}_2)}{n(\text{HCl})} = \frac{1}{2}$  and  $n(\text{HCl}) = 0.730 \times 0.02945 = 0.0215 \text{ mol}$  and  $n(\text{H}_2) = 0.01075 \text{ mol}$   
 $m(\text{H}_2) = 0.01075 \times 2 = 0.0215 \text{ g}$
- ii**  $\frac{n(\text{H}_2)}{n(\text{Zn})} = \frac{1}{1}$  and  $n(\text{Zn}) = 0.0239 \text{ mol}$  so  $n(\text{H}_2) = 0.0239 \text{ mol}$   
 $m(\text{H}_2) = 0.0239 \times 2 = 0.0478 \text{ g}$

**A34.**

- a** **i**  $n(\text{KI}) = 1.0 \text{ mol}$  and  $n(\text{Pb}(\text{NO}_3)_2) = 1.0 \text{ mol}$   
 $\frac{n(\text{Pb}(\text{NO}_3)_2)}{n(\text{KI})} = \frac{1}{2} = 0.5$  and  $n(\text{Pb}(\text{NO}_3)_2)$  required = 0.5 mol but  $n(\text{Pb}(\text{NO}_3)_2)$  available = 1 mol  
 All KI will be used and  $\text{Pb}(\text{NO}_3)_2$  is in excess. So  $\text{Pb}(\text{NO}_3)_2$  is in excess by  $(1.0 - 0.5) = 0.5 \text{ mol}$
- ii**  $n(\text{KI}) = 0.50 \text{ mol}$  and  $n(\text{Pb}(\text{NO}_3)_2) = 2 \text{ mol}$   
 $\frac{n(\text{Pb}(\text{NO}_3)_2)}{n(\text{KI})} = \frac{1}{2}$  and  $n(\text{Pb}(\text{NO}_3)_2)$  required = 0.25 mol but  $n(\text{Pb}(\text{NO}_3)_2)$  available = 2 mol  
 So all KI will be used and  $\text{Pb}(\text{NO}_3)_2$  is in excess by  $(2.0 - 0.25) = 1.75 \text{ mol} = 1.8 \text{ mol}$ .
- iii**  $n(\text{KI}) = 3 \text{ mol}$  and  $n(\text{Pb}(\text{NO}_3)_2) = 1.5 \text{ mol}$   
 $\frac{n(\text{Pb}(\text{NO}_3)_2)}{n(\text{KI})} = \frac{1}{2}$  and  $n(\text{Pb}(\text{NO}_3)_2)$  required = 1.5 mol but  $n(\text{Pb}(\text{NO}_3)_2)$  available = 1.5 mol  
 So all  $\text{Pb}(\text{NO}_3)_2$  and all the KI will be used. So neither reactant is in excess.
- b** **i**  $n(\text{KI}) = 0.00602 \text{ mol}$  and  $n(\text{Pb}(\text{NO}_3)_2) = 0.00302 \text{ mol}$   
 $\frac{n(\text{Pb}(\text{NO}_3)_2)}{n(\text{KI})} = \frac{1}{2}$  and  $n(\text{Pb}(\text{NO}_3)_2)$  required = 0.00301 mol but  $n(\text{Pb}(\text{NO}_3)_2)$  available = 0.00302 mol  
 So all KI will be used and  $\text{Pb}(\text{NO}_3)_2$  is in excess by a very small amount  $(0.00302 - 0.00301) = 0.00001 \text{ mol}$



A balanced equation shows that 1 mol of  $\text{PbI}_2$  precipitate will form for every 2 mol of KI that reacts.

$$\frac{n(\text{PbI}_2)}{n(\text{KI})} = \frac{1}{2} \text{ and } n(\text{PbI}_2) = \frac{0.00602}{2} = 0.00301 \text{ mol so } m(\text{PbI}_2) = 0.00301 \times 461 = 1.39 \text{ g}$$

- ii  $n(\text{KI}) = 0.01566 \text{ mol}$  and  $n(\text{Pb}(\text{NO}_3)_2) = 0.00181 \text{ mol}$

$$\frac{n(\text{KI})}{n(\text{Pb}(\text{NO}_3)_2)} = \frac{2}{1} \text{ and } n(\text{KI}) \text{ required} = 2 \times n(\text{Pb}(\text{NO}_3)_2) = 2 \times 0.00181 = 0.00362 \text{ mol}$$

$n(\text{KI})$  available = 0.01566 mol so all  $\text{Pb}(\text{NO}_3)_2$  will be used and KI is in excess by:

$$0.01566 - 0.00362 = 0.01204 \text{ mol}$$

A balanced equation shows that 1 mol of  $\text{PbI}_2$  precipitate will form for every 2 mol of KI that reacts.

$$\frac{n(\text{PbI}_2)}{n(\text{Pb}(\text{NO}_3)_2)} = \frac{1}{1} \text{ and } n(\text{PbI}_2) = 0.00181 \text{ mol so } m(\text{PbI}_2) = 0.00181 \times 461 = 0.84 \text{ g}$$

- iii  $n(\text{KI}) = 0.00361 \text{ mol}$  and  $n(\text{Pb}(\text{NO}_3)_2) = 0.00785 \text{ mol}$

$$\frac{n(\text{Pb}(\text{NO}_3)_2)}{n(\text{KI})} = \frac{1}{2} \text{ \& } n(\text{Pb}(\text{NO}_3)_2) \text{ required} = 0.001805 \text{ mol but } n(\text{Pb}(\text{NO}_3)_2) \text{ available} = 0.00785 \text{ mol}$$

So all KI will be used and  $\text{Pb}(\text{NO}_3)_2$  is in excess by  $0.00785 - 0.001805 = 0.006045 \text{ mol}$

$$\frac{n(\text{PbI}_2)}{n(\text{KI})} = \frac{1}{2} \text{ and } n(\text{PbI}_2) = \frac{0.00361}{2} = 0.001805 \text{ mol so } m(\text{PbI}_2) = 0.001805 \times 461 = 0.83 \text{ g}$$

### A35.

- a  $n(\text{P}_4\text{O}_6) = 0.0200 \text{ mol}$  and  $n(\text{I}_2) = 0.01182 \text{ mol}$

$$\frac{n(\text{I}_2)}{n(\text{P}_4\text{O}_6)} = \frac{8}{5} \text{ and } n(\text{I}_2) \text{ required} = 0.0320 \text{ mol but } n(\text{I}_2) \text{ available} = 0.01182 \text{ mol}$$

So there is insufficient  $\text{I}_2$  to react with all the  $\text{P}_4\text{O}_6$ .  $\text{I}_2$  is the limiting reagent and  $\text{P}_4\text{O}_6$  is in excess.

Use  $n(\text{I}_2)$  provided to find  $n(\text{P}_4\text{O}_6)$  needed to react completely with the  $\text{I}_2$ . From the equation, 8 mol of  $\text{I}_2$  reacts with 5 mol of  $\text{P}_4\text{O}_6$ .

$$n(\text{P}_4\text{O}_6) \text{ required} = 0.00738 \text{ mol but } n(\text{P}_4\text{O}_6) \text{ available} = 0.0200 \text{ mol}$$

$$\text{So } \text{P}_4\text{O}_6 \text{ is in excess by } 0.0200 - 0.00738 = 0.0126 \text{ mol so } m(\text{P}_4\text{O}_6) \text{ in excess} = 0.0126 \times 220 = 2.78 \text{ g}$$

- b Use the amount of the limiting reagent,  $\text{I}_2$ , to determine the amount of  $\text{P}_2\text{I}_4$  formed. From the equation, 8 mol of  $\text{I}_2$  reacts to form 4 mol of  $\text{P}_2\text{I}_4$ .

$$n(\text{P}_2\text{I}_4) = 4 \text{ and } n(\text{I}_2) = 8$$

$$\text{So } n(\text{P}_2\text{I}_4) = \frac{4 \times 0.01182}{8} \text{ mol} = 0.00591 \text{ mol so } m(\text{P}_2\text{I}_4) = 0.00591 \times 569.6 = 3.37 \text{ g}$$

- c Use the amount of the limiting reagent,  $\text{I}_2$ , to determine the amount of  $\text{P}_4\text{O}_{10}$  formed. From the equation, 8 mol of  $\text{I}_2$  reacts to form 3 mol of  $\text{P}_4\text{O}_{10}$ .

$$n(\text{P}_4\text{O}_{10}) = 3 \text{ and } n(\text{I}_2) = 8$$

$$\text{So } n(\text{P}_4\text{O}_{10}) = \frac{3 \times 0.01182}{8} \text{ mol} = 0.00443 \text{ mol so } m(\text{P}_4\text{O}_{10}) = 0.00443 \times 284.0 = 1.26 \text{ g}$$

- d Total mass of products =  $3.37 + 1.26 = 4.63 \text{ g}$

4.63 g of products formed plus 2.78 g unreacted  $\text{P}_4\text{O}_6 = 7.40 \text{ g}$ , which is consistent with the total mass of reactants used initially.

### A36.

- a  $n(\text{CaO}) = 0.3209 \text{ mol}$  and  $n(\text{C}) = 1.00 \text{ mol}$

$$\frac{n(\text{C})}{n(\text{CaO})} = \frac{3}{1} \text{ and } n(\text{C}) \text{ required} = 3 \times n(\text{MgSO}_4) = 3 \times 0.309 \text{ mol} = 0.963 \text{ mol but } n(\text{C}) \text{ available} = 1.00 \text{ mol}$$

So all CaO will be used (and is the limiting reagent) and C is in excess by:  $1.00 - 0.963 = 0.037 \text{ mol}$

$$m(\text{C}) \text{ in excess} = 0.0374 \times 12 = 0.449 \text{ g}$$

- b Use the amount of the limiting reagent, CaO, to determine the amount of  $\text{CaC}_2$  formed. From the equation, 1 mol of  $\text{CaC}_2$  is formed from 1 mol of CaO.

$$\frac{n(\text{CaC}_2)}{n(\text{CaO})} = \frac{1}{1} \text{ and } n(\text{CaC}_2) = 0.3209 \text{ mol so } m(\text{CaC}_2) = 0.3209 \times 64.1 = 20.6 \text{ g}$$

### A37.

- $n(\text{PbS}) = 4.180 \text{ mol}$  and  $n(\text{C}) = 4.167 \text{ mol}$

$$\frac{n(\text{PbS})}{n(\text{C})} = \frac{2}{1} \text{ and } n(\text{C}) \text{ required} = n(\text{PbS}) = 4.180 \text{ mol so } n(\text{C}) \text{ available} = 4.167 \text{ mol}$$

$$\frac{n(\text{Pb})}{n(\text{C})} = \frac{2}{2} = \frac{1}{1} \text{ and } n(\text{Pb}) = n(\text{C}) = 4.167 \text{ mol so } m(\text{Pb}) = 4.167 \times 207.2 = 863 \text{ g}$$

**A38.**

$$n(\text{Zn}) = 0.765 \text{ mol and } n(\text{HCl}) = 1.00 \times 0.100 = 0.100 \text{ mol}$$

$$\frac{n(\text{HCl})}{n(\text{Zn})} = \frac{2}{1} \text{ and } n(\text{HCl}) \text{ required} = 2 \times n(\text{Zn}) = 2 \times 0.765 = 0.153 \text{ mol so } n(\text{HCl}) \text{ available} = 0.100 \text{ mol}$$

So there is insufficient HCl to react with all the Zn. HCl is the limiting reagent and Zn is in excess.

$$\text{a } \frac{n(\text{ZnCl}_2)}{n(\text{HCl})} = \frac{1}{2} \text{ and } n(\text{HCl}) = 0.050 \text{ mol so } m(\text{ZnCl}_2) = 0.050 \times 136.4 = 6.82 \text{ g}$$

$$\text{b } \frac{n(\text{H}_2)}{n(\text{HCl})} = \frac{1}{2} \text{ and } n(\text{H}_2) = 0.050 \text{ mol so } m(\text{H}_2) = 0.050 \times 2.00 = 0.10 \text{ g}$$

**A39.**

$$\text{a } n(\text{Zn}) = 0.0492 \text{ mol and } n(\text{CuSO}_4) = 0.500 \times 0.200 = 0.100 \text{ mol}$$

$$\text{b } \frac{n(\text{CuSO}_4)}{n(\text{Zn})} = \frac{1}{1} \text{ and } n(\text{CuSO}_4) \text{ required} = n(\text{Zn}) = 0.0492 \text{ mol but } n(\text{CuSO}_4) \text{ available} = 0.100 \text{ mol}$$

So all Zn will be used (it's the limiting reagent) and CuSO<sub>4</sub> is in excess by 0.100 – 0.0492 = 0.0508 mol

$$\frac{n(\text{Cu})}{n(\text{Zn})} = \frac{1}{1} \text{ and } n(\text{Cu}) \text{ formed} = n(\text{Zn}) = 0.0492 \text{ mol so } m(\text{Cu}) = 0.0492 \times 63.5 = 3.13 \text{ g}$$

$$\text{c } n(\text{CuSO}_4) \text{ in excess after reaction (from above)} = 0.0508 \text{ mol}$$

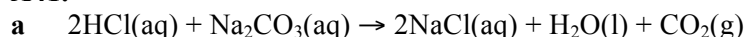
$$\text{The volume of the solution is 200 mL or 0.200 L so } c(\text{CuSO}_4) = \frac{0.0508 \text{ mol}}{0.200 \text{ L}} = 0.254 \text{ mol L}^{-1}$$

**A40.**

$$\text{b } c(\text{K}_2\text{CO}_3) = 0.03556 \text{ M (to 4 significant figures)}$$

$$\text{c } \frac{n(\text{H}_2\text{SO}_4)}{n(\text{Na}_2\text{CO}_3)} = \frac{1}{1} \text{ and } n(\text{H}_2\text{SO}_4) = 0.03556 \text{ M} \times 0.02000 \text{ L} = 0.0007113 \text{ mol}$$

$$c(\text{H}_2\text{SO}_4) = 0.0007113 \text{ mol} / 0.02256 \text{ L} = 0.0315 \text{ M}$$

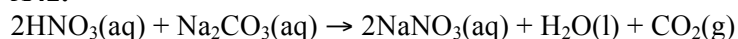
**A41.**

$$\text{b } c(\text{Na}_2\text{CO}_3) = 0.05125 \text{ M (four significant figures)}$$

$$\text{c } \frac{n(\text{HCl})}{n(\text{Na}_2\text{CO}_3)} = \frac{2}{1} \text{ and } n(\text{HCl}) = 2 \times 0.05125 \text{ M} \times 0.02000 \text{ L} = 0.002050 \text{ mol}$$

$$c(\text{HCl}) = 0.002050 \text{ mol} / 0.02024 \text{ L} = 0.1013 \text{ M}$$

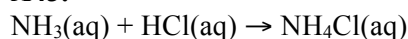
d Approximately half the volume would be used.

**A42.**

$$\text{a } c(\text{Na}_2\text{CO}_3) = 0.04166 \text{ M (to 4 significant figures)}$$

$$\text{b } \frac{n(\text{HNO}_3)}{n(\text{Na}_2\text{CO}_3)} = \frac{2}{1} \text{ and } n(\text{HNO}_3) = 2 \times 0.04166 \text{ M} \times 0.02000 \text{ L} = 0.001666 \text{ mol}$$

$$c(\text{HNO}_3) = 0.001666 \text{ mol} / 0.02347 \text{ L} = 0.07100 \text{ M}$$

**A43.**

$$\text{a } n(\text{HCl}) = 0.0892 \text{ M} \times 0.02135 \text{ L} = 0.001904 \text{ mol}$$

$$\text{b } \frac{n(\text{NH}_3)}{n(\text{HCl})} = \frac{1}{1} \text{ and } n(\text{NH}_3) \text{ in } 20.00 \text{ mL} = 0.001904 \text{ mol}$$

$$\text{c } n(\text{NH}_3) \text{ in } 250.0 \text{ mL} = 0.001904 \times 250 / 20 = 0.02381 \text{ mol}$$

$$\text{d } m(\text{NH}_3) \text{ in the original } 23.27 \text{ g} = 0.02381 \text{ mol} \times 17.0 \text{ g mol}^{-1} = 0.405 \text{ g}$$

$$\text{e } \% \text{ NH}_3 \text{ in the original solution} = \frac{0.405}{23.27} \times 100 = 1.74\%$$

Yes, it is less than 4% by mass, as claimed.

**A44.**

- a**  $\text{Pb}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{PbSO}_4(\text{aq})$
- b** Masses of reactants and products can be calculated only from the formula of the substance being weighed or determined, that is the molecular or empirical formula for the compound.

**A45.**

- a**  $\text{CaCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
- b** Step 1: Calculate mass of calcium carbonate in chalk.  $m = 96.8\%$  of chalk = 3.34 g  
Step 2: Calculate amount, in mol, of calcium carbonate.  $n = 0.0334$  mol
- c** Step 1: Use mole ratios to determine amount of hydrochloric acid.  
Ratio is 2 : 1, so  $n(\text{HCl}) = 2 / 1 \times 0.0334 = 0.0667$  mol  
Step 2: Calculate volume of hydrochloric acid.  $V = 0.267$  L = 267 mL
- d** Step 1: Calculate amount, in mol, of hydrochloric acid.  $n = cV = 0.25 \times 0.075 = 0.019$  mol  
Step 2: Use mole ratios to determine amount of calcium carbonate.  
Ratio is 1 : 2, so  $n(\text{CaCO}_3) = \frac{1}{2} \times 0.019 = 0.0094$  mol  
Step 3: Calculate mass of calcium carbonate.  $m = nM = 0.0094 \times 100.1 = 0.94$  g  
Step 4: Calculate mass of chalk.  $m = 100/96.8 \times 0.94 = 0.97$  g
- e** colouring, adhesive

**A46.**

A wide range of student responses is possible.

**A47.**

- a** Weigh out a known mass of lead nitrate. Dissolve the lead nitrate completely in de-ionised water, using the smallest volume practicable. Add potassium iodide solution until, on the addition of further potassium iodide, no more yellow precipitate forms. Filter the lead iodide from the solution, dry the precipitate and weigh it. Calculate the amount of lead nitrate used and the amount of lead iodide obtained. Compare these two values.
- b** Incomplete precipitation of lead iodide; loss of precipitate during filtration; incomplete drying of the precipitate.
- c** Wear a laboratory coat and safety glasses; wear disposable gloves; do not ingest chemicals.
- d** **i** Lead iodide is formed.  
**ii** The particles in the solids do not move freely and so the contact necessary for a reaction to occur is limited.

**Chapter 16 Redox chemistry and corrosion****A1.**

- a** oxidation                      **b** reduction                      **c** reduction                      **d** oxidation

**A2.**

- a**  $\text{Fe}(\text{s}) \rightarrow \text{Fe}^{3+}(\text{aq}) + 3\text{e}^-$  oxidation                      **b**  $\text{K}(\text{s}) \rightarrow \text{K}^+(\text{aq}) + \text{e}^-$  oxidation
- c**  $\text{F}_2(\text{g}) + 2\text{e}^- \rightarrow 2\text{F}^-(\text{aq})$  reduction                      **d**  $\text{O}_2(\text{g}) + 4\text{e}^- \rightarrow 2\text{O}^{2-}(\text{aq})$  reduction

**A3.**

- a**  $\text{Fe}(\text{s})$  has been oxidised to  $\text{Fe}^{2+}(\text{aq})$                       **b**  $\text{Fe}(\text{s}) \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^-$                       **c**  $\text{H}^+(\text{aq})$
- d**  $\text{H}^+(\text{aq})$  has been reduced to  $\text{H}_2$                       **e**  $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$                       **f**  $\text{Fe}(\text{s})$

**A4.**

- a** Magnesium is oxidised, copper ions are reduced.                      **b**  $\text{Mg}(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{e}^-$
- c**  $\text{Cu}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s})$                       **d**  $\text{Mg}(\text{s}) + \text{Cu}^{2+}(\text{aq}) \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{Cu}(\text{s})$
- e** oxidant  $\text{Cu}^{2+}$ ; reductant Mg
- f** The solution loses some of its blue colour due to the loss of  $\text{Cu}^{2+}(\text{aq})$ , which react to form  $\text{Cu}(\text{s})$ .

**A5.**

- a**  $\text{Cu}^{2+}$                       **b** Cu                      **c**  $\text{Fe}^{2+}$

**A6.**

- a** CaO                      **b** Ca(s)                      **c**  $\text{Ca}(\text{s}) \rightarrow \text{Ca}^{2+}(\text{s}) + 2\text{e}^-$                       **d**  $\text{O}_2(\text{g})$
- e**  $\text{O}_2(\text{g}) + 4\text{e}^- \rightarrow 2\text{O}^{2-}(\text{s})$                       **f**  $2\text{Ca}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{CaO}(\text{s})$

g oxidised, oxygen, oxygen, calcium, reduced, calcium, calcium, oxygen

## A7.

a	Ni = +4	b	C = +2	c	C = +4	d	Br = 0	e	N = -2
f	S = +6	g	N = +5	h	C = -4	i	O = 0	j	P = +5
k	S = -2	l	Cr = +3						

## A8.

- a lead reduced (+2 to 0), magnesium oxidised (0 to +2)  
 b mercury reduced (+2 to 0), oxygen oxidised (-2 to 0)  
 c oxygen oxidised (-2 to 0), fluorine reduced (0 to -1)  
 d manganese reduced (+7 to +2), iron oxidised (+2 to +3)

## A9.

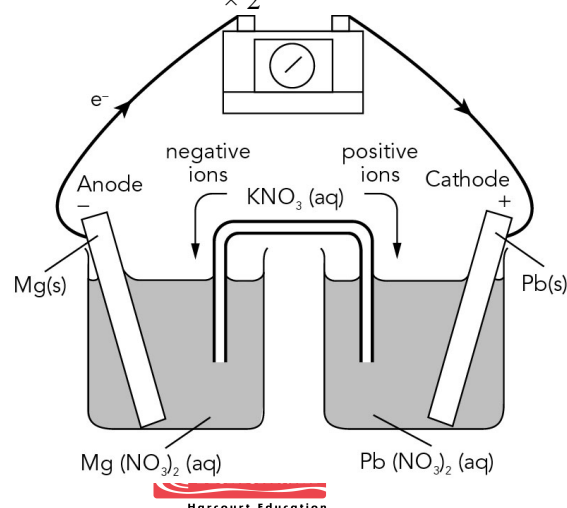
- a Step 1: Balance all atoms in the half equation except oxygen.  $\text{SO}_4^{2-} \rightarrow \text{SO}_2$   
 Step 2: Balance the oxygen atoms by adding water molecules.  $\text{SO}_4^{2-} \rightarrow \text{SO}_2 + 2\text{H}_2\text{O}$   
 Step 3: Balance the hydrogen atoms by adding  $\text{H}^+$  ions (in acidic solution).  $\text{SO}_4^{2-} + 4\text{H}^+ \rightarrow \text{SO}_2 + 2\text{H}_2\text{O}$   
 Step 4: Balance the charge by adding  $\text{e}^-$  to the more positive side.  $\text{SO}_4^{2-} + 4\text{H}^+ + 2\text{e}^- \rightarrow \text{SO}_2 + 2\text{H}_2\text{O}$   
 Step 5: Add symbols of state.  $\text{SO}_4^{2-}(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{SO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l})$   
 b  $\text{H}_2\text{O}_2(\text{aq}) \rightarrow \text{O}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- (\text{aq})$   
 c  $\text{H}_2\text{S}(\text{g}) \rightarrow \text{S}(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- (\text{aq})$   
 d  $\text{MnO}_4^-(\text{aq}) + 4\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{MnO}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l})$   
 e  $\text{Ta}_2\text{O}_5(\text{s}) + 10\text{H}^+(\text{aq}) + 10\text{e}^- \rightarrow 2\text{Ta}(\text{s}) + 5\text{H}_2\text{O}(\text{l})$   
 f  $\text{SO}_3^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{SO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$   
 g  $\text{IO}_3^-(\text{aq}) + 6\text{H}^+(\text{aq}) + 6\text{e}^- \rightarrow \text{I}^-(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$

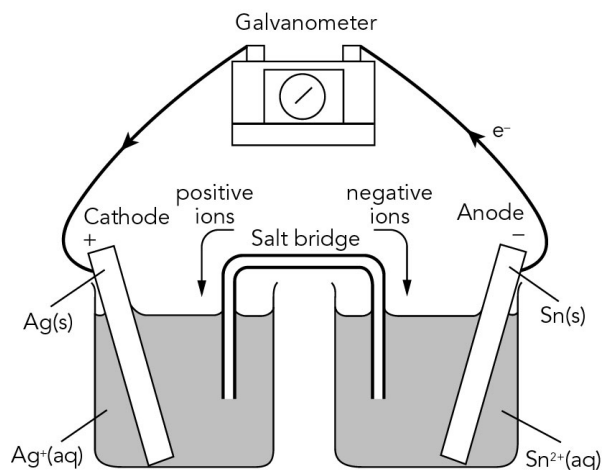
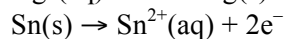
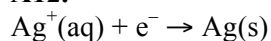
## A10.

- a  $\text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow 2\text{H}_2\text{O}(\text{l})$   $\times 4$   
 $\text{PbS}(\text{s}) + 4\text{H}_2\text{O}(\text{l}) \rightarrow \text{PbSO}_4(\text{s}) + 8\text{H}^+(\text{aq}) + 8\text{e}^-$   $\times 1$   
 Overall:  $4\text{H}_2\text{O}_2(\text{aq}) + \text{PbS}(\text{s}) \rightarrow \text{PbSO}_4(\text{s}) + 4\text{H}_2\text{O}(\text{l})$   
 b  $\text{I}_2(\text{aq}) + 2\text{e}^- \rightarrow 2\text{I}^-(\text{aq})$   
 $\text{H}_2\text{S}(\text{g}) \rightarrow \text{S}(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$   
 Overall:  $\text{I}_2(\text{aq}) + \text{H}_2\text{S}(\text{g}) \rightarrow 2\text{I}^-(\text{aq}) + \text{S}(\text{s}) + 2\text{H}^+(\text{aq})$   
 c  $\text{SO}_3^{2-}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{SO}_4^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$   $\times 5$   
 $\text{MnO}_4^-(\text{aq}) + 8\text{H}^+(\text{aq}) + 5\text{e}^- \rightarrow \text{Mn}^{2+}(\text{aq}) + 4\text{H}_2\text{O}(\text{l})$   $\times 2$   
 Overall:  $5\text{SO}_3^{2-}(\text{aq}) + 2\text{MnO}_4^-(\text{aq}) + 6\text{H}^+(\text{aq}) \rightarrow 5\text{SO}_4^{2-}(\text{aq}) + 2\text{Mn}^{2+}(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$   
 d  $\text{NO}(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{NO}_3^-(\text{aq}) + 4\text{H}^+(\text{aq}) + 3\text{e}^-$   $\times 2$   
 $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^- \rightarrow 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$   
 Overall:  $2\text{NO}(\text{g}) + \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 6\text{H}^+(\text{aq}) \rightarrow 2\text{NO}_3^-(\text{aq}) + 2\text{Cr}^{3+}(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$   
 e  $\text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$   $\times 3$   
 $\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) + 6\text{e}^- \rightarrow 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$   
 Overall:  $3\text{Zn}(\text{s}) + \text{Cr}_2\text{O}_7^{2-}(\text{aq}) + 14\text{H}^+(\text{aq}) \rightarrow 3\text{Zn}^{2+}(\text{aq}) + 2\text{Cr}^{3+}(\text{aq}) + 7\text{H}_2\text{O}(\text{l})$   
 f  $\text{CuO}(\text{s}) + 2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{Cu}(\text{s}) + \text{H}_2\text{O}(\text{l})$   $\times 5$   
 $\text{NH}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{NO}(\text{g}) + 5\text{H}^+(\text{aq}) + 5\text{e}^-$   $\times 2$   
 Overall:  $5\text{CuO}(\text{s}) + 2\text{NH}_3(\text{aq}) \rightarrow 5\text{Cu}(\text{s}) + 2\text{NO}(\text{g}) + 3\text{H}_2\text{O}(\text{l})$

## A11.

- a  
 b  $\text{Mg}(\text{s}) \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{e}^-$   
 $\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Pb}(\text{s})$   
 Overall:  $\text{Mg}(\text{s}) + \text{Pb}^{2+}(\text{aq}) \rightarrow \text{Mg}^{2+}(\text{aq}) + \text{Pb}(\text{s})$   
 c lead electrode is the cathode; magnesium electrode is the anode  
 d Anions will migrate to the  $\text{Mg}^{2+}(\text{aq})/\text{Mg}(\text{s})$  half cell, cations to the  $\text{Pb}^{2+}(\text{aq})/\text{Pb}(\text{s})$  half cell.



**A12.****A13.**

For reactions to occur spontaneously, the cation must be a stronger oxidant than the cation of the metal added.

- a No      b No      c Yes      d Yes      e Yes      f Yes      g No

**A14.**

Use iron and lead to test the solutions. The copper(II) nitrate will react with both iron and lead.

The tin nitrate will react only with the iron. The zinc nitrate will not react with either of the metals.

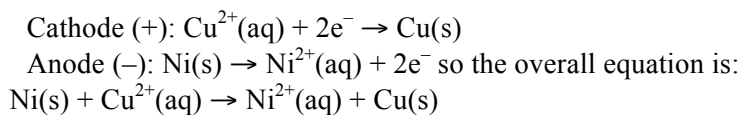
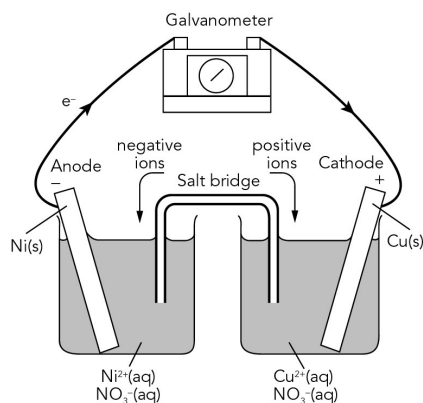
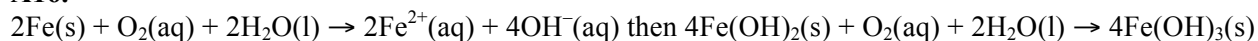
**A15.**

**i**

Cathode (+):  $\text{Ag}^+(\text{aq}) + \text{e}^- \rightarrow \text{Ag}(\text{s})$   
 Anode (-):  $\text{Zn}(\text{s}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$   
 Overall:  $\text{Zn}(\text{s}) + 2\text{Ag}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{Ag}(\text{s})$

**ii**

Cathode (+):  $\text{Pb}^{2+}(\text{aq}) + 2\text{e}^- \rightarrow \text{Pb}(\text{s})$   
 Anode (-):  $\text{Fe}(\text{s}) \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^-$   
 Overall:  $\text{Fe}(\text{s}) + \text{Pb}^{2+}(\text{aq}) \rightarrow \text{Fe}^{2+}(\text{aq}) + \text{Pb}(\text{s})$

**iii****A16.**

**A17.**

Near the coast, moisture in the air contains a higher amount of dissolved salts (e.g. NaCl(aq)). Salts are good electrolytes and accelerate the rusting process. They do this because they facilitate the production of ions at the oxidation and reduction sites of a corroding metal.

**A18.**

- a** magnesium and zinc  
**b** Only metals more reactive (i.e. more easily oxidised) than iron will act as sacrificial anodes. These more reactive metals will be oxidised in preference to the iron. The iron will become the cathode (the site of reduction) and no oxidation of the iron will take place.

**A19.**

Reduction of oxygen occurs when there is plenty of moisture and the oxygen concentration is high—that is, at or just above the surface of the water. A cathodic region forms here. The anodic region, then, is close to the cathode and where the oxygen concentration is less—that is, just below the surface. Oxidation, or corrosion, therefore occurs more rapidly below the surface.

**A20.**

As zinc is more reactive than steel, it will be the anode and steel will be the cathode. Oxidation, and so corrosion, of the nails will thus be prevented.

**Chapter review****A21.**

- a** Oxidation is the gain of oxygen atoms; reduction is the loss of oxygen atoms.  
**b** Oxidation is the loss of electrons; reduction is the gain of electrons.  
**c** Oxidation involves an increase in oxidation number; reduction a decrease in oxidation number

**A22.**

- a** oxidation                      **b** oxidation                      **c** reduction                      **d** reduction

**A23.**

- a** Mg(s) oxidised, Cu<sup>2+</sup>(aq) reduced                      **b** Zn(s) oxidised, Ag<sup>+</sup>(aq) reduced  
**c** CO(g) oxidised, PbO(s) reduced                      **d** Ca(s) oxidised, H<sup>+</sup>(aq) reduced  
**e** Fe(s) oxidised, Pb<sup>2+</sup>(aq) reduced

**A24.**

Group A will be oxidised because metals tend to lose electrons to non-metals when they react. Group B will be reduced because non-metals tend to gain electrons when they react.

**A25.**

- a** All are redox reactions  
**b** **i** C oxidised, CO<sub>2</sub> reduced                      **ii** Cl<sub>2</sub> reduced, H<sub>2</sub>S oxidised  
**iii** H<sub>2</sub>O<sub>2</sub> oxidised and reduced                      **iv** Fe<sup>2+</sup> oxidised, MnO<sub>4</sub><sup>-</sup> reduced  
**v** Cd oxidised, NiO<sub>2</sub> reduced                      **vi** Fe(OH)<sub>2</sub> oxidised, H<sub>2</sub>O<sub>2</sub> reduced

**A26.**

- a** 0                      **b** +2                      **c** +5                      **d** +7                      **e** +2 +6                      **f** +6  
**g** +3                      **h** +2                      **i** +7                      **j** 0

**A27.**

- a** +5                      **b** +5                      **c** +4                      **d** +4                      **e** +3                      **f** +2  
**g** +1                      **h** 0                      **i** -2                      **j** -3                      **k** -3                      **l** -3

**A28.**

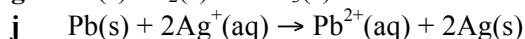
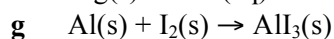
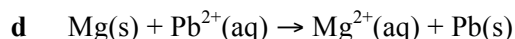
Carbon in carbon dioxide is reduced, oxygen in water is oxidised.

**A29.**

- a** zinc                      **b**  $\text{Zn(s)} \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{e}^-$                       **c** H<sup>+</sup>(aq)                      **d**  $2\text{H}^+(\text{aq}) + 2\text{e}^- \rightarrow \text{H}_2(\text{g})$   
**e** Zn(s)                      **f** H<sup>+</sup>(aq)                      **g**  $\text{Zn(s)} + 2\text{HCl(aq)} \rightarrow \text{ZnCl}_2(\text{aq}) + \text{H}_2(\text{g})$

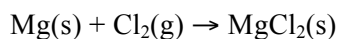
**A30.**

- a**  $\text{Zn(s)} + 2\text{Ag}^+(\text{aq}) \rightarrow \text{Zn}^{2+}(\text{aq}) + 2\text{Ag(s)}$                       **b** no reaction                      **c** no reaction



**e** no reaction

**f** no reaction



**i** no reaction

**A31.**

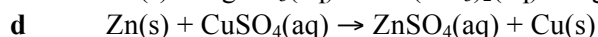
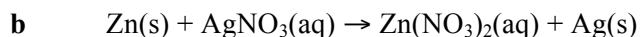
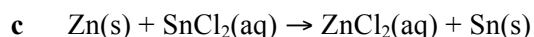
Place 10 mL of each solution into a clean test-tube. Add a small piece of magnesium ribbon to each solution. The magnesium should be coated by displaced metal in the silver nitrate and lead nitrate solutions, but not in the sodium nitrate. The lead coating will be black turning silver. To confirm this, take a fresh sample and add a small piece of copper. Copper will displace silver from the solution, giving silver deposit and a blue solution. Copper will not displace lead from the solution.

**A32.**

zinc

**A33.**

**a** no



**A34.**

$\text{F}^-$ , Ag,  $\text{I}^-$ , Cu, Sn, Ni, Mg, Li

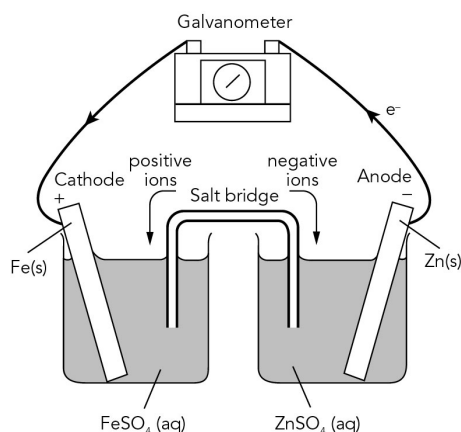
**A35.**

**a** all

**b** Nitrogen in  $\text{NH}_3$  is oxidised in stage 1. Nitrogen in NO is oxidised in stage 2. Some nitrogen in  $\text{NO}_2$  is oxidised and some is reduced in stage 3. Oxygen is reduced in stages 1 and 2.

**c** Oxidants: oxygen and nitrogen. Reductant: nitrogen.

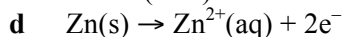
**A36.**



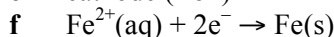
**a**

**b** from the zinc to the iron

**c** anode (zinc)

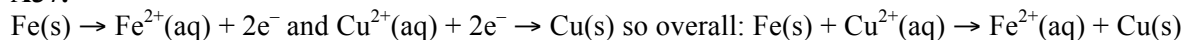


**e** cathode (iron)



**h** A salt bridge is needed to complete the circuit and to maintain electrical neutrality in the half cells.

**A37.**

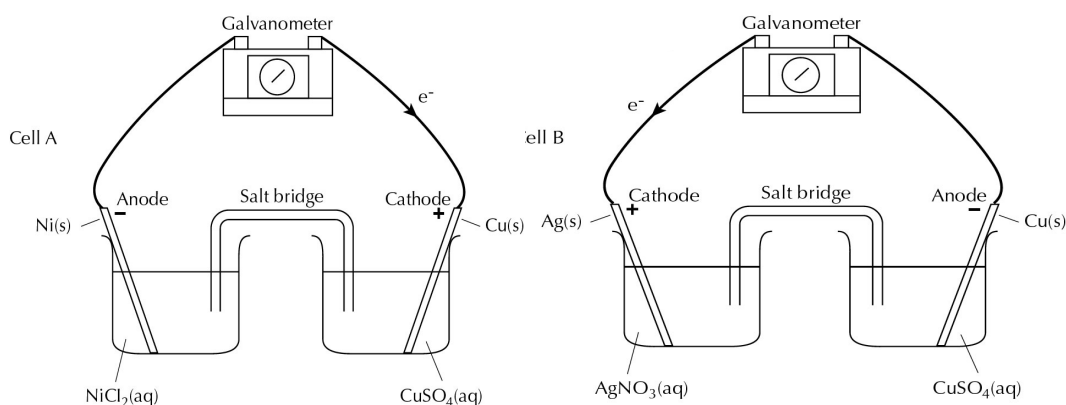
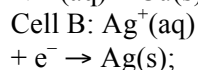
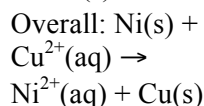
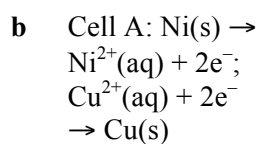


**A38.**

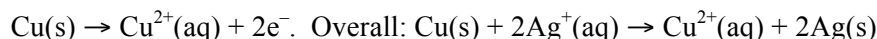
Since the zinc electrode is the negative electrode, electrons must be released there. Therefore, zinc metal must be oxidised. Metal X must be less reactive than zinc.

**A39.**

**a**



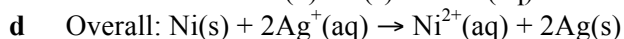
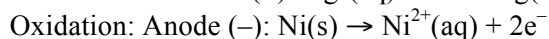
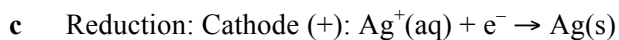
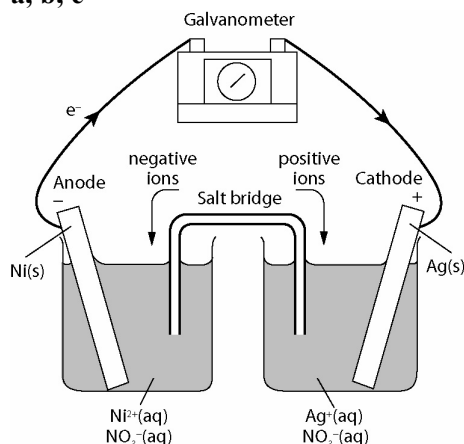




- c The polarity of the copper electrode depends on its reactivity relative to the reactivity of the other metal to which it is connected. Copper is a weaker reductant than nickel, so the copper electrode is positive in cell A. However, copper is a stronger reductant than silver, so copper is the negative electrode in cell B.

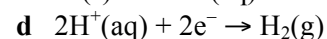
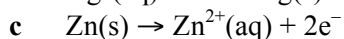
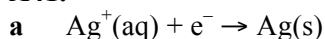
A40.

a, b, e

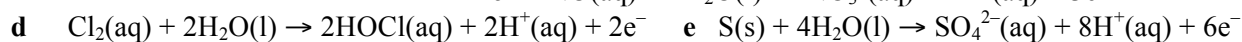
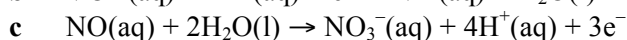
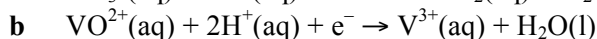
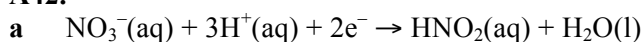


f the Ni electrode

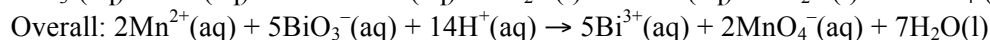
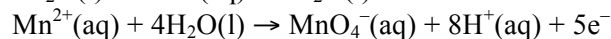
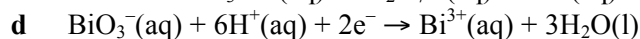
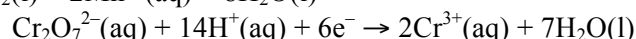
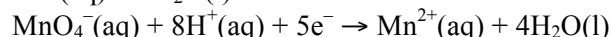
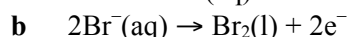
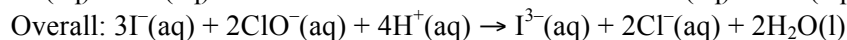
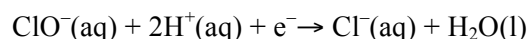
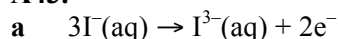
A41.



A42.



A43.



A44.

Cathodic protection involves protection of a metal, usually iron, by making it the cathode of a cell. The metal can either be joined to a more reactive metal, such as zinc, or be connected to the negative terminal of a DC power source.

A45.

Copper is not a very reactive metal and so is not easily oxidised.

A46.

- a Tin is not very reactive and so does not corrode readily. It protects the steel layer under it from corroding by preventing its contact with water and oxygen.
- b Zinc is too reactive to be used inside food cans. It would be oxidised easily by the contents of the can and so contaminate the food.
- c If a can is dented, the tin layer may be cracked, exposing the steel underneath to the contents of the can. The steel forms an anode and the tin, which is less reactive, forms the cathode. The steel rapidly corrodes and contaminates the food. Rust that forms may flake off, leaving a hole in the can.

A47.

Any coating on a nail is likely to crack when the nail is used. If the coating is tin, the tin will form a cathode to the more reactive iron. The iron will be oxidised (corrode). Zinc, however, being more reactive than iron, will be the anode and iron will be the cathode. Oxidation, and so corrosion, of the iron nail will be prevented.

A48.

Near the seaside, moisture in the air contains a higher amount of dissolved salts (e.g.  $\text{NaCl(aq)}$ ). Salts are good electrolytes and accelerate the rusting process. They do this because they facilitate the production of ions at the

oxidation and reduction sites of a rusting metal.

**A49.**

- a** Given the high electronegativity of oxygen, the reaction of another element (fluorine excepted) with oxygen always results in the complete or partial transfer of electrons from the other element to the oxygen. This means the other element either loses one or more electrons or undergoes an increase in oxidation number as it gains oxygen—all are definitions of oxidation.
- b** This definition has been extended/replaced because it excludes many reactions that are similar to the reaction of an element with oxygen.

**A50.**

- a** It is soluble in water. Neither the nitrate ion nor the potassium ion will take part in the redox reactions within the half cells and neither will form a precipitate with any other ions in solution. (All potassium salts and all nitrates are soluble in water.)
- b** Calcium carbonate has an extremely low solubility in water and so will not provide ions in solution that can migrate from the salt bridge. The circuit will not be complete.

**A51.**

Individual students' responses required.

## Chapter 17 Green chemistry

**AE1.**

- a** At 1 atm pressure, and below the triple point, must be solid.
- b** At 1 atm pressure, and above the triple point, must be gas.
- c** At 10 atm pressure, and  $-70^{\circ}\text{C}$ , must be solid.
- d** At  $0^{\circ}\text{C}$  and 10 atm, from the graph (interpolating between  $-60^{\circ}\text{C}$  and  $31.1^{\circ}\text{C}$ , and a bit higher than 7.9 atm), must be gas.

## Chapter review

**A1.**

Individual students' responses required.

**A2.**

Formula of reactants	Molar mass of reactants	Atoms used in product	Sum of molar mass of used atoms	Unused atoms	Sum of molar mass of unused atoms
$\text{C}_6\text{H}_6$	78.0	6C, 6H	78.0		
$2\text{NaOH}$	80.0	O	16.0	2Na, O, 2H	64.0
$\text{H}_2\text{SO}_4$	98.1	—	—	2H, S, 4O	98.1
Total atoms in reactants: 6C, 10 H, 6O, 2Na, S	256.1	6C, 6H, O	94.0	2Na, 4H, S, 5O	162.1

$$\text{Percentage atom economy} = \frac{\text{molar mass used atoms}}{\text{molar mass of all reactants}} \times \frac{100}{1} = \frac{94.0}{256.1} \times \frac{100}{1} = 36.7\%$$

**A3.**

For reaction 1:

Formula of reactants	Molar mass of reactants	Atoms used in product	Sum of molar mass of used atoms	Unused atoms	Sum of molar mass of unused atoms
$\text{C}_2\text{H}_4$	28.0	2C, 4H	28	—	
$2\text{Cl}_2$	141.8	—	—	4Cl	141.8
$\text{Ca}(\text{OH})_2$	74.1	—	—	Ca, 2O, 2H	74.1
$\text{H}_2\text{O}$	18.0	O	16	2H	2.0
Total atoms in reactants: 2C, 8H, 3O, Ca, 4Cl	261.9	6C, 6H, O	44.0	4Cl, 4H, Ca, 2O	217.9

$$\text{Percentage atom economy} = \frac{\text{molar mass used atoms}}{\text{molar mass of all reactants}} \times \frac{100}{1} = \frac{44.0}{261.9} \times \frac{100}{1} = 16.8\%$$

For reaction 2:

All the atoms are incorporated in the product. So percentage atom economy = 100%

**A4.**

Some factors would include:

- The difference between the atom economies of each process
- The degree of hazard of the starting material
- Whether the hazardous material in the second method can be degraded into a benign compound

**A5.**

- |  |   |
|--|---|
| <b>a</b> safer, or no, solvents        | <b>b</b> increasing energy efficiency   |
| <b>c</b> atom economy, use of solvents | <b>d</b> use of renewable raw materials |

**A6. To A9.**

Individual students' responses required

## Unit 2 Area of Study 1 review

### Multiple-choice questions

**A1.**

A. Water requires a large amount of heat to evaporate. In an evaporative cooler, that heat comes from the surroundings, leaving them cooler.

**A2.**

C. As water expands on freezing, the density of ice is lower than that of liquid water and so ice will float on liquid water.

**A3.**

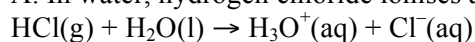
D. When passing through a cation exchange resin, metal ions become attached to negative groups on the ion exchange resin, displacing  $H^+$  ions.

**A4.**

B

**A5.**

A. In water, hydrogen chloride ionises according to the equation:



**A6.**

C. Because ethanol has a lower heat capacity than water, it will take less heat to raise its temperature by each degree.

**A7.**

D. At  $0^\circ C$ , a maximum of 4 g will dissolve in 100 g water. So the maximum mass that will dissolve in 20 g water:  $\frac{4}{100} \times 20 \text{ g} = 0.8 \text{ g}$  so the mass that crystallises out is:  $6.0 - 0.8 = 5.2 \text{ g}$

**A8.**

B

Step 1: Calculate amount of copper sulfate required:  $n = cV = 0.500 \times 0.200 = 0.100 \text{ mol}$

Step 2: Calculate mass of copper sulfate required.  $m = n \times M = 0.100 \times (63.5 + 32.1 + (4 \times 16))$   
 $= 0.100 \times 159.6 = 15.96 \text{ g}$

**A9.**

D

Step 1: Calculate  $[OH^-]$ :  $[OH^-] = [NaOH] = 1.0 \text{ M}$

Step 2: Calculate  $[H_3O^+]$ :  $[H_3O^+] = 10^{-14}$

Step 3: Calculate pH.  $pH = -\log_{10}[H_3O^+] = -\log_{10}(10^{-14}) = 14$

**A10.**

D. A Brønsted–Lowry reaction requires a proton transfer to occur.

**A11.**

A.  $\text{Fe}^{2+}$  ions give away electrons to form  $\text{Fe}^{3+}$  ions. These electrons reduce the  $\text{Ag}^+$  ions.

**A12.**

A. If tin(II) ions act as the oxidant, then Mg must be oxidised (i.e. lose electrons) to form  $\text{Mg}^{2+}(\text{aq})$ .

**A13.**

D. A base is a proton acceptor. A weak base ionises to a small extent.

**A14.**

D. Each mole of NaCl produces 1 mole of chloride ions. Each mole of  $\text{AlCl}_3$  produces 3 mole of chloride ions. The solution, therefore, contains 4 mole chloride ions in 1 L solution.

**A15.**

D.  $\text{Sn}^{4+}(\text{aq})$  has gained 2 electrons, so has been reduced. The electrons have been donated by the  $\text{Pb}(\text{s})$ , so  $\text{Pb}(\text{s})$  has caused the reduction and is therefore the reducing agent.

**Short-answer questions****A16.**

- a**
- i** The energy required to raise the temperature of 1 g of the substance by  $1^\circ\text{C}$ .
  - ii**  $E = 250 \text{ g} \times 4.18 \text{ J g}^{-1} \text{ }^\circ\text{C}^{-1} \times (100 - 18)^\circ\text{C} = 85\,690 \text{ J} = 86 \text{ kJ}$  (to 2 significant figures)
- b**
- i**  $\text{KCl}(\text{s}) \rightarrow \text{K}^+(\text{aq}) + \text{Cl}^-(\text{aq})$ ; the KCl dissociates into ions
  - ii**  $\text{C}_2\text{H}_5\text{OH}(\text{l}) \rightarrow \text{C}_2\text{H}_5\text{OH}(\text{aq})$ ;  $\text{C}_2\text{H}_5\text{OH}(\text{l})$  dissolves by forming hydrogen bonds with water
  - iii**  $\text{CH}_3\text{COOH}(\text{l}) \rightarrow \text{CH}_3\text{COO}^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$ ;  $\text{CH}_3\text{COOH}(\text{l})$  ionises in water
- c** The bonds between water molecules (hydrogen bonds) are stronger than the dispersion forces that might form between the non-polar octane and water.
- d**
- |                            |                             |
|----------------------------|-----------------------------|
| potassium nitrate: soluble | aluminium chloride: soluble |
| lead sulfate: insoluble    | silver chloride: insoluble  |
- e**
- i**  $2\text{AgNO}_3(\text{aq}) + \text{MgCl}_2(\text{aq}) \rightarrow 2\text{AgCl}(\text{s}) + \text{Mg}(\text{NO}_3)_2(\text{aq})$  :       $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl}(\text{s})$
  - ii**  $\text{CuCl}_2(\text{aq}) + \text{Na}_2\text{CO}_3(\text{aq}) \rightarrow \text{CuCO}_3(\text{s}) + 2\text{NaCl}(\text{aq})$ :       $\text{Cu}^{2+}(\text{aq}) + \text{CO}_3^{2-}(\text{aq}) \rightarrow \text{CuCO}_3(\text{s})$
  - iii** no reaction

**A17.**

- a**
- i** The steps should be arranged in this order: C, B, E, D or G, I, A, F or H.
  - ii** Step 1:  $\text{HNO}_3(\text{aq}) + \text{KOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{KNO}_3(\text{aq})$   
The balanced equation shows that 1 mol of acid reacts with 1 mol of the base, i.e.  $\frac{n(\text{KOH})}{n(\text{HNO}_3)} = 1$ .  
Step 2: Use the formula  $n = cV$  (where  $n$  is the amount in moles,  $c$  is the concentration in  $\text{mol L}^{-1}$  and  $V$  is the volume of the solution in L).  
Initially  $n(\text{HNO}_3) = 0.100 \times 0.025 = 0.0025 \text{ mol}$   
Initially  $n(\text{KOH}) = 0.200 \times 0.030 = 0.0060 \text{ mol}$   
Step 3: From the mole ratio, 0.0025 mol of  $\text{HNO}_3$  will all be consumed. Therefore, KOH is in excess. As the ratio is 1 : 1, 0.0025 mol of  $\text{HNO}_3$  will be used.  
 $\therefore n(\text{HNO}_3) \text{ in excess} = n(\text{HNO}_3) \text{ initially} - n(\text{HNO}_3) \text{ used} = 0.0060 - 0.0025 \text{ mol} = 0.0035 \text{ mol}$   
Step 4: As  $\text{HNO}_3$  is a monoprotic acid,  $[\text{HNO}_3] = [\text{H}_3\text{O}^+] = 0.0035 \text{ mol}$   
Step 5: The total volume of the system was  $25.0 + 30.0 = 55.0 \text{ mL} = 0.055 \text{ L}$   
Step 6:  $[\text{OH}^-] = 0.0636 = 10^{-1.196} \text{ M}$   
Step 7:  $[\text{H}_3\text{O}^+] = 10^{-12.8} \text{ M}$   
Step 8:  $\text{pH} = 12.8$
- b**
- i** Step 1:  $\text{HCl}(\text{aq}) + \text{NaOH}(\text{aq}) \rightarrow \text{H}_2\text{O}(\text{l}) + \text{NaCl}(\text{aq})$   
The balanced equation shows that 1 mol of acid reacts with 1 mol of the base, i.e.  $\frac{n(\text{NaOH})}{n(\text{HCl})} = 1$ .  
Step 2: Initially  $n(\text{HCl}) = 0.200 \times 0.020 = 0.0040 \text{ mol}$   
Initially  $n(\text{NaOH}) = 0.300 \times 0.010 = 0.0030 \text{ mol}$   
Step 3: From the mole ratio, 0.003 mol of NaOH will all be consumed. Therefore, HCl is in excess. As the ratio is 1 : 1, 0.003 mol of HCl will be used.

$$\therefore n(\text{HCl}) \text{ in excess} = n(\text{HCl}) \text{ initially} - n(\text{HCl}) \text{ used} = 0.0040 - 0.0030 \text{ mol} = 0.0010 \text{ mol}$$

Step 4: As HCl is a monoprotic acid,  $[\text{HCl}] = [\text{H}_3\text{O}^+] = 0.0010 \text{ mol}$

Step 5: Total volume of the system =  $10.0 + 20.0 = 30.0 \text{ mL} = 0.0300 \text{ L}$

Step 6:  $[\text{H}_3\text{O}^+] = 0.0333 = 10^{-1.477} \text{ M}$

Step 7:  $\therefore [\text{H}_3\text{O}^+] = 10^{-1.477} \text{ M}$

Step 8:  $\therefore \text{pH} = 1.5$

ii Step 1:  $\text{H}_2\text{SO}_4(\text{aq}) + 2\text{KOH}(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{K}_2\text{SO}_4(\text{aq})$

This balanced molecular equation shows that 1 mol of sulfuric acid reacts with 2 mol of the strong base, KOH.  $\frac{n(\text{KOH})}{n(\text{H}_2\text{SO}_4)} = \frac{2}{1}$

Step 2: Initially  $n(\text{H}_2\text{SO}_4) = 0.50 \times 0.100 = 0.050 \text{ mol}$

Initially  $n(\text{KOH}) = 0.20 \text{ mol}$

Step 3: From the mole ratio,  $n(\text{KOH}) = 0.100 \text{ mol}$ . Therefore, KOH is in excess.

$n(\text{KOH}) \text{ used} = 2 \times n(\text{H}_2\text{SO}_4) = 0.100 \text{ mol}$

$\therefore n(\text{KOH}) \text{ in excess} = n(\text{KOH}) \text{ initially} - n(\text{KOH}) \text{ used} = 0.20 - 0.10 \text{ mol} = 0.10 \text{ mol}$

Step 4:  $[\text{KOH}] = [\text{OH}^-] = 0.10 \text{ mol}$

Step 5: The total volume of the system was  $100 \text{ mL} = 0.100 \text{ L}$  (Assume the volume does not change when the solid KOH was added.)

Step 6:  $[\text{OH}^-] = 1.0 \text{ M}$

Step 7:  $[\text{H}_3\text{O}^+] = 10^{-14} \text{ M}$

Step 8:  $\text{pH} = 14$

### Q18.

Some of the problems in this Area of Study have required you to take a number of steps, with each step requiring an understanding of a particular concept. For each of the following types of problems, summarise the steps you would take to reach a solution.

For example, a question that asked you to convert an amount of water to a mass of water could be summarised as follows:

amount of  $\text{H}_2\text{O}$  (mol)  $\xrightarrow{\times M}$  mass of  $\text{H}_2\text{O}$  (g)

- Given a mass of NaCl, calculate the amount of NaCl.
- Given a mass of  $\text{CaCl}_2$ , calculate the amount of  $\text{Cl}^-$  ions present.
- Given an amount of chloride ions, calculate the mass of aluminium chloride required to produce them.
- Given a mass of NaCl and a volume of solution, calculate the molarity of sodium ions in solution.
- Given a mass of HCl and a volume of solution, calculate the pH of the solution.
- Given a mass of ethane ( $\text{C}_2\text{H}_6$ ), calculate the number of ethane molecules present

### A18.

A  $n(\text{NaCl}) = m(\text{NaCl}) / M(\text{NaCl})$

b  $n(\text{Cl}^-) = 2 \times n(\text{CaCl}_2) = 2 \times n(\text{Cl}^-)$ ,

c  $n(\text{AlCl}_3) = 3 \times n(\text{Cl}^-)$  then  $m(\text{AlCl}_3) = n(\text{AlCl}_3) \times M(\text{AlCl}_3)$  in  $\text{g mol}^{-1}$

d  $n(\text{NaCl}) = \frac{m(\text{NaCl}) \text{ in g}}{M(\text{NaCl}) \text{ in g mol}^{-1}}$  then,  $n(\text{Na}^+) = n(\text{NaCl})$  and so  $[\text{Na}^+] = n(\text{NaCl})$  in mol/volume (L)

e  $n(\text{HCl}) = m(\text{HCl}) / M(\text{HCl})$  then  $n(\text{H}^+) = n(\text{HCl})$  and so  $[\text{H}^+] = n(\text{H}^+)$  in mol/volume in L;  $\text{pH} = -\log_{10}[\text{H}^+]$

f  $n(\text{ethane}) = m(\text{ethane}) / M(\text{methane})$  then No. of ethane molecules = amount of ethane in mol  $\times N_A$

### A19.

a  $\text{CaCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$

$\text{MgCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$

$\text{Al}(\text{OH})_3(\text{s}) + 3\text{HCl}(\text{aq}) \rightarrow \text{AlCl}_3(\text{aq}) + 3\text{H}_2\text{O}(\text{l})$

b The molar mass of  $\text{CaCO}_3 = 40 + 12 + 48 = 100 \text{ g mol}^{-1}$

The molar mass of  $\text{MgCO}_3 = 24 + 12 + 48 = 84 \text{ g mol}^{-1}$

The molar mass of  $\text{Al}(\text{OH})_3 = 27 + 3 + 48 = 78 \text{ g mol}^{-1}$

The balanced equation (from part a) shows that 1 mol of calcium carbonate neutralises 2 mol of hydrochloric acid.

The balanced equation (from part b) shows that 1 mol of magnesium carbonate neutralises 2 mol of hydrochloric acid.

The balanced equation (from part a) shows that 1 mol of aluminium hydroxide neutralises 3 mol of

hydrochloric acid,

Now,  $n(\text{HCl}) = 2 \times n(\text{CaCO}_3) = 0.015 \text{ mol}$

$n(\text{HCl})$  neutralised by 2 tablets  $= 2 \times 0.015 = 0.030 \text{ mol}$

Now,  $n(\text{HCl}) = 2 \times n(\text{MgCO}_3) = 0.0029 \text{ mol}$

$n(\text{HCl})$  neutralised by 2 tablets  $= 2 \times 0.0029 = 0.0057 \text{ mol}$

Now,  $n(\text{HCl}) = 3 \times n(\text{Al}(\text{OH})_3) = 0.0046 \text{ mol}$

$n(\text{HCl})$  neutralised by 2 tablets  $= 2 \times 0.0046 = 0.0092 \text{ mol}$

Total  $n(\text{HCl})$  neutralised by 2 tablets  $= 0.030 + 0.0057 + 0.0092 = 0.0449 \text{ mol}$  or  $4.49 \times 10^{-2} \text{ mol}$

c  $V = 4.49 \text{ L} = 4.5 \text{ L}$

d The carbonate salts in the tablets react with HCl in your stomach to produce carbon dioxide. This gas is insoluble in the acidic mixture in your stomach. Pressure in the stomach builds up and the gas is eventually forced up into your oesophagus.

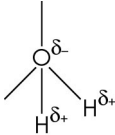
#### A20.

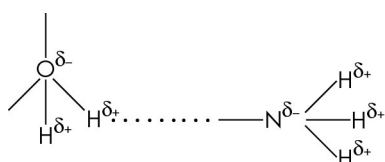
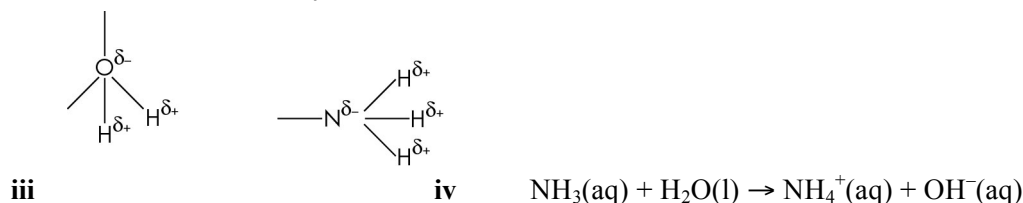
- a Nitric acid is a covalent molecular compound. Ions are not present, so it will not conduct electricity. When placed in water, it will ionise, producing  $\text{H}^+(\text{aq})$  and  $\text{NO}_3^-(\text{aq})$  ions.  
 $\text{HNO}_3(\text{l}) \rightarrow \text{H}^+(\text{aq}) + \text{NO}_3^-(\text{aq})$
- b The partially negatively charged oxygen atom ( $\text{O}^\delta-$ ) of the water molecule will be attracted towards positively charged magnesium ions, whereas the partially positively charged hydrogen atoms ( $\text{H}^\delta+$ ) of the water molecule will be attracted towards the negatively charged chloride ions.
- c The bonds that are involved in attracting water molecules to each other in both the solid and the liquid states are intermolecular hydrogen bonds, which are weaker than ionic bonds. These bonds occur between molecules. Strong covalent bonds occur within the molecules. In sodium chloride, the strong ionic bonds extend in three dimensions throughout the lattice.
- d Heat is needed to change solid water to liquid water. This comes from the surrounding air and ground, leaving it cooler

#### A21.

- a A strong acid is one that donates its proton readily. HCl is completely ionised in water, so is a strong acid in water. Concentration refers to the amount of acid in a given volume of solution. A solution of 10 M HCl is a concentrated solution of a strong acid. 0.01 M HCl is a dilute solution of a strong acid.
- b Dissociation involves the separations of ions already present in a compound (i.e. from an ionic compound such as NaCl) when the compound dissolves in water. Ionisation is said to occur when a compound that is not made up of ions (i.e. a covalent molecular compound such as HCl) reacts with water to produce ions.
- c  $\text{H}_2\text{SO}_4$  is a diprotic acid because it can donate two protons to a base.  $\text{HSO}_4^-$  ion is amphiprotic because it can act as an acid to donate its proton to a base or act as a base and accept a proton from an acid.
- d In a solution of salt water, the salt (solute) has been dissolved in the water (solvent).
- e In osmosis, water molecules pass through a membrane from an area of low salt concentration to one of higher salt concentration. In reverse osmosis, pressure is used to force water molecules to pass through a membrane from an area of high salt concentration to one of lower salt concentration.

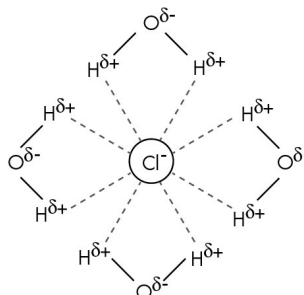
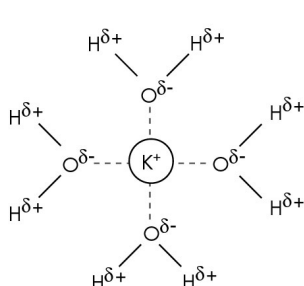
#### A22.

- a i  $\text{O } 1s^2 2s^2 2p^4$ ,  $\text{S } 1s^2 2s^2 2p^6 3s^2 3p^4$  ii  iii oxygen
- iv hydrogen +1 oxygen -2 v covalent bonds
- vi The two non-bonding pairs and the two bonding pairs of electrons repel. The most stable arrangement is tetrahedral. The shape of the molecule is dependent on the position of the atoms present. Only two of the four tetrahedral positions are occupied by hydrogen atoms, giving the molecule a bent shape.
- vii The water molecule is highly polar. Hydrogen bonds exist between water molecules and these require more energy to overcome than the dipole-dipole attraction between the less polar hydrogen sulfide molecules.
- b i ii Ammonia is very polar and forms hydrogen bonds with water.



$\text{NH}_4^+$  is the conjugate acid of  $\text{NH}_3$ .

- a i 2,8,8,1 or  $1s^2 2s^2 2p^6 3s^2 3p^4 4s^1$  ii 2,8,7 or  $1s^2 2s^2 2p^6 3s^2 2p^5$   
 b i Solid potassium is a metallic lattice of  $\text{K}^+$  cations surrounded by a sea of electrons.  
 ii Gaseous chlorine,  $\text{Cl}_2$ , is a diatomic covalent molecule.  
 iii KCl solid is an ionic lattice of  $\text{K}^+$  cations and  $\text{Cl}^-$  anions.  
 c i *Dissociate* means that the ions in the lattice separate.  
 ii  $\text{KCl}(\text{s}) \rightarrow \text{K}^+(\text{aq}) + \text{Cl}^-(\text{aq})$   
 d Bonds broken are the ionic bonds in the KCl lattice and hydrogen bonds between water molecules.  
 e The bonds are ion–dipole attractions.



---- Represents ion–dipole interaction

- f i Solubility = mass of KCl in 100 g water =  $\frac{45.5}{130} \times 100 = 35.0 \text{ g/100 g water}$   
 ii Step 1: Find total mass of the solution containing 45.5 g KCl so  $45.5 + 130 = 175.5 \text{ g}$   
 Step 2: Find volume of solution containing 45.5 g KCl.  
 As the density of the solution is taken to be  $1 \text{ g mL}^{-1}$ , then the volume of 175.5 g of solution will be 175.5 mL (0.1755 L).  
 Step 3: Calculate the amount of KCl in mole so Amount = 0.603 mol  
 Step 4: Calculate the concentration in  $\text{mol L}^{-1} = 3.43 \text{ mol L}^{-1}$   
 g Less soluble because oil is non-polar and so would not be attracted to ions.  
 h Ionic bond in lead sulfate is stronger as it is due to the attraction between ions with a charge of 2+ and 2– as opposed to the singly charged ions in KCl.  
 i i  $\text{KCl}(\text{aq}) + \text{AgNO}_3(\text{aq}) \rightarrow \text{AgCl}(\text{s}) + \text{KNO}_3(\text{aq})$  ii  $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl}(\text{s})$   
 iii silver chloride  
 j All potassium and nitrate compounds are water soluble, so would not form precipitates with contents of half cells. There are some insoluble chlorides.

#### A24.

- a Step 1: Calculate amount, in mol, of sodium hydrogen carbonate.  
 $n = cV = 0.200 \times 0.0500 = 0.0100 \text{ mol}$   
 Step 2: Calculate mass of sodium hydrogen carbonate.  $m = nM = 0.0100 \times 84 = 0.84 \text{ g}$   
 b i Step 1: Write a balanced equation:  $\text{HCl}(\text{aq}) + \text{NaHCO}_3(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$   
 ii Step 2: Calculate amount, in mol, of sodium hydrogen carbonate.  
 $n = cV = 0.023 \times 0.0500 = 0.0012 \text{ mol}$   
 Step 3: Use mole ratios to determine amount of hydrochloric acid.  
 Ratio is 1 : 1, so  $n(\text{HCl}) = 0.0012 \text{ mol}$   
 Step 4: Calculate concentration of hydrochloric acid.  
 $c = 0.033 \text{ M}$



iii Convert  $\text{mol L}^{-1}$  to  $\text{g L}^{-1}$  so  $c = 0.033 \times 36.5 = 1.2 \text{ g L}^{-1}$

iv Step 1: Calculate amount, in mol, of hydrochloric acid.  $n = cV = 0.033 \times 0.03 = 9.9 \times 10^{-4} \text{ mol}$

Step 2: Calculate the number of chloride ions. No. ions  $= 9.9 \times 10^{-4} \times 6.02 \times 10^{23} = 6.0 \times 10^{20}$  ions

### A25.

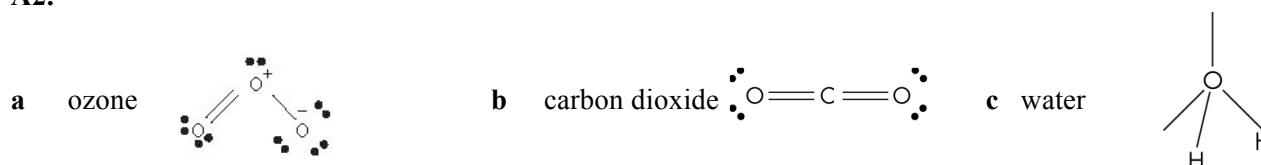
- a Tin forms a thin layer of oxide on its outside surface, which is impervious to air and water, and is relatively unreactive. Once this initial layer forms, further corrosion does not occur, or only proceeds very slowly.
- b Galvanised iron is not used to make food cans because the zinc can react readily with the contents of the can, thus contaminating them.
- c i  $\text{Fe(s)} \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^{-}$  ii  $\text{Mg(s)} \rightarrow \text{Mg}^{2+}(\text{aq}) + 2\text{e}^{-}$
- iii sacrificial anode
- iv This method works because magnesium is below iron in the electrochemical series. Therefore, magnesium atoms will lose electrons more readily than iron atoms, and so will corrode in preference to the iron, thus protecting the iron.

## Chapter 18 The atmosphere

### A1.

The part that supports life is called the biosphere.

### A2.



Carbon dioxide is linear in shape. Ozone has one lone pair of electrons. The two bonding sets of electrons and the lone pair are as far apart as possible at an angle of  $120^\circ$ . The shape of the molecule is determined by the position of the atoms. So ozone is V-shaped, with the oxygen atoms forming an angle of about  $120^\circ$ . Water has two lone pairs of electrons. The two bonding pairs of electrons and the two lone pairs (a total of four electron pairs) are as far apart as possible, forming a tetrahedral configuration. Water is V-shaped, with the angle between the two hydrogens about  $109^\circ$ .

### A3.

ozone

### A4.

Oxygen has a double bond (the angle in ozone is intermediate between a double and a single bond).

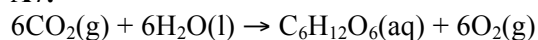
### A5.

carbon dioxide

### A6.

The nitrogen molecule is too stable for plants to use atmospheric nitrogen directly. Nitrogen fixation is the conversion of atmospheric nitrogen into a form that is usable by plant. Bacteria in the soil convert nitrogen into soluble  $\text{NO}_3^-$  and  $\text{NH}_4^+$  ions. Plants need a continual supply of nitrogen to produce compounds needed in the plant cells.

### A7.

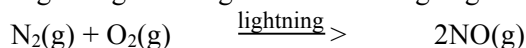


### A8.

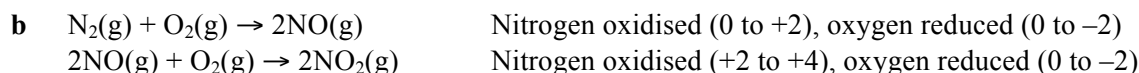
The triple covalent bond between the two nitrogen atoms in a nitrogen molecule is very strong. A large amount of energy must be provided to break this bond if nitrogen is to react.

### A9.

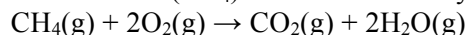
- a Lightning discharges convert nitrogen gas to nitrogen(II) oxide gas.



Nitrogen(II) oxide gas reacts with oxygen to form nitrogen(IV) oxide gas.  $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$

**AE1.**

The methane ( $\text{CH}_4$ ) combines with oxygen ( $\text{O}_2$ ) to form carbon dioxide ( $\text{CO}_2$ ) and water ( $\text{H}_2\text{O}$ ).

**AE2.**

Total biomass-generating capacity (from Table 18.2 on page 321) =  $54.5 + 11.0 + 8.2 + 7.9 + 7.2 + 6.9 + 3.8 + 2.2 + 1.0 + 1.0 = 103.7$  MW

Percentage contributed by each site =  $100 \times (\text{capacity of each site}) \div (\text{total capacity})$

So for Maryvale, % =  $100 \times 54.5 \div 103.7 = 52.555 \div 48 \div 41 \approx 52.56\%$

Similarly, Clayton 10.61%; Sunshine 7.91%; Springvale 7.62%; Berwick 6.94%; Broadmeadows 6.65%; Werribee 3.66%; Brooklyn 2.12%; Corio 0.96%; Wyndham 0.96%.

**AE3.**

Students' own responses.

**AE4.**

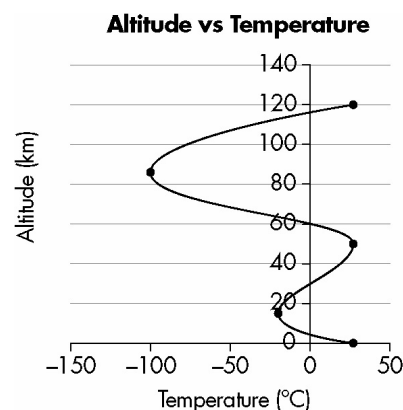
noise, large exposed areas needed, visual pollution, possible environmental impact including wildlife

**Chapter review****A10.**

From Figure 18.2, a table of values can be drawn up.

Temperature ( $^{\circ}\text{C}$ )	27	-20	27	-100	27
Altitude (km)	0	15	50	86	120

These values can be plotted on a graph with temperature on the horizontal axis and altitude on the vertical axis.

**A11.**

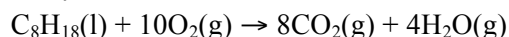
- a** ultraviolet;  $\text{O}_3(\text{g}) \rightarrow \text{O}_2(\text{g}) + \text{O}(\text{g})$ ; radiation
- b** ultraviolet;  $\text{O}_2(\text{g}) \rightarrow 2\text{O}(\text{g})$ ; radiation; ultraviolet;  $\text{O}_3(\text{g}) \rightarrow \text{O}_2(\text{g}) + \text{O}(\text{g})$ ; radiation
- c** UV radiation causes skin cancer, deterioration of plastics and reduction of plant growth.
- d** stratosphere

**A12.**

Combustion of fossil fuels, plant decay.

**A13.**

- a** A number of atmospheric gases, including carbon dioxide, are capable of absorbing infrared radiation re-radiated from the surface of the Earth. This warms the air nearer the Earth. This has meant that, over millions of years, life on Earth has been able to evolve at temperatures much warmer than would otherwise have been the case.
- b** Carbon dioxide, methane, water vapour, nitrogen(I) oxide and CFCs.

**A14.****A15.**

- a** More carbon dioxide is released into the atmosphere and the destroyed forest cannot absorb carbon dioxide.
- b** More carbon dioxide is released into the atmosphere.
- c** Less carbon dioxide is released into the atmosphere.

**A16.**

**a** Mass  $\text{N}_2 = 3.3 \times 10^{-2} \times 28 = 0.92$  g

Mass  $\text{O}_2 = 8.3 \times 10^{-3} \times 32 = 0.27$  g

$$\text{Mass Ar} = 2.5 \times 10^{-4} \times 39.9 = 0.010 \text{ g}$$

- b** Total mass =  $0.92 + 0.27 + 0.010 = 1.2 \text{ g}$   
**c** Density = mass/volume =  $1.2/1.00 = 1.2 \text{ g L}^{-1}$

**A17.**

Carbon dioxide is used in photosynthesis—the process can provide us with all our food.

**A18.**

nitrogen fixation

**A19.**

The atmosphere is important because it contains the gases oxygen and carbon dioxide, which are essential for life processes of respiration and photosynthesis; it absorbs harmful ultraviolet radiation; it maintains a stable climate by trapping some of the heat radiated from the Earth's surface; and it holds water vapour, which is an essential part of the water cycle.

**A20.**

- a** Oxygen is required for the process of respiration in living things—plants and animals.  
**b** Ozone in the stratosphere absorbs harmful ultraviolet radiation, which can have a damaging effect on living things.  
**c** Water vapour in the atmosphere plays a vital part in our weather patterns. Water is essential to living things.  
**d** Carbon dioxide is used by green plants to make their food in the process of photosynthesis. Animals ultimately depend on plants as their food source.  
**e** Methane is an important greenhouse gas.

**A21.**

There are many possible and individual answers to this question. The strength of a concept map is that it will identify incorrect ideas.

## Chapter 19 Environmental issues

**A1.**

The  $\text{SO}_2$  produced by human activity is highly concentrated in populated areas.

**A2.**

- a**  $\text{HNO}_3(\text{aq})$  is more acidic because strong acids ionise to a greater extent, and so release more  $\text{H}^+(\text{aq})$  ions.  
**b**  $\text{HNO}_2(\text{aq})$  has the higher pH. Weaker acids release fewer  $\text{H}^+(\text{aq})$  and so would have higher pH values (at equal concentrations).

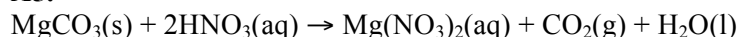
**A3.**

100 times more acidic. Because the pH scale is logarithmic, each pH unit indicates a tenfold increase in pH.

**A4.**

- a**  $\text{:N} \equiv \text{N:}$   
**b** The triple bond between nitrogen atoms is very strong, so high temperatures are needed to break it and initiate the reaction to form NO.

**A5.**



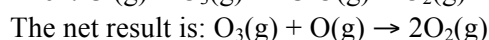
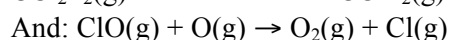
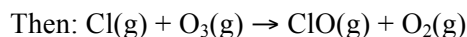
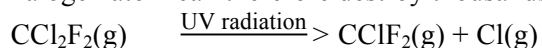
**A6.**

- a**  $\text{O}_3$   
**b** Both ozone and oxygen (sometimes known as dioxygen) contain only oxygen atoms. However, they have different properties due to the different arrangement of oxygen atoms in the two substances. They are therefore allotropes.

**A7.**

- a** In the presence of ultraviolet light, CFCs decompose to produce free halogen atoms that react with ozone.

The important feature of these reactions is the regeneration of halogen atoms at the end of the cycle. One halogen atom can therefore destroy thousands of ozone molecules.



- b** Collect and reuse CFCs from old refrigerators and air conditioners; reduce use of aerosol cans or find alternative propellants; find alternatives to foaming agents used to produce materials such as polystyrene foam for packaging.

### A8.

- a** Primary pollutants of photochemical smog are nitrogen(II) oxide, nitrogen(IV) oxide and unburnt hydrocarbons.
- b** Primary pollutants are largely produced from the combustion processes in internal combustion engines. At the high temperatures reached in these engines, nitrogen from the air reacts with oxygen to form nitrogen oxides. If the air : fuel ratio in engines is reduced, the formation of nitrogen oxides is limited but larger amounts of unburnt hydrocarbons are emitted in the exhaust gases.
- c** Secondary pollutants include ozone, aldehydes and PAN (peroxyacetyl nitrate). These pollutants irritate the eyes and respiratory systems of humans. They also damage plants.

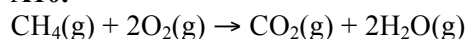
### A9.

- a** A number of atmospheric gases, including carbon dioxide, are capable of absorbing infrared radiation re-radiated from the surface of the Earth. This warms the air nearer the Earth. This has meant that, over millions of years, life on Earth has been able to evolve at temperatures much warmer than would otherwise have been the case.
- b** carbon dioxide, methane, water vapour, nitrogen(I) oxide and CFCs
- c** The concentration of carbon dioxide has been increasing since the Industrial Revolution due to increasing consumption of fossil fuels. Methane is produced by ruminant animals such as sheep and cattle; its concentration has increased as a result of increased animal populations. Methane is also produced by decomposing rubbish; more methane is therefore produced as the amount of rubbish dumped increases. Nitrogen(I) oxide concentrations are increasing as a result of increased use of internal combustion engines. If the average temperature of the Earth increases, the amount of water vapour in the atmosphere will also increase and make the problem worse.
- d** Increased levels of carbon dioxide, methane and chlorofluorocarbons in the atmosphere cause an increase in the average temperature of the Earth, causing a change in the rainfall patterns. Sea levels will rise, flooding low-lying countries and coastal land.

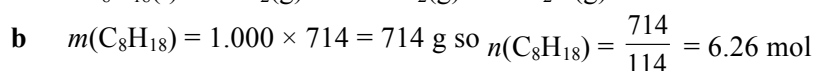
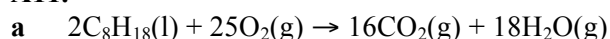
**e**

Source of greenhouse gas	1990 level (%)
Energy	$(408 - 286) \times 100/286 = 42.7$
Agricultural	12.9
Waste	0
Industrial processes	55.8
Land use change	-66.7

### A10.



### A11.



From the equation,  $n(\text{CO}_2) = 8 \times 6.26 = 50.1 \text{ mol}$  so  $m(\text{CO}_2) = n \times M = 50.10 \times 44 = 2205 \text{ g} = 2.205 \text{ kg}$

## Chapter review

### A12.

- a** Ozone is caused by any electrical discharge in the atmosphere.
- b** Ozone can have serious health effects, but in the upper atmosphere it shields life from ultraviolet radiation.

**A13.**

Cars produce carbon dioxide, which is thought to contribute to the greenhouse effect. Primary pollutants from car exhausts also contribute to photochemical smog. However, these problems occur in the lower atmosphere. Reactions that result in the destruction of the ozone layer occur in the stratosphere and are not due to car emissions.

**A14.**

- a**    **i**     $2\text{C}_2\text{H}_6(\text{g}) + 7\text{O}_2(\text{g}) \rightarrow 4\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{g})$   
      **ii**    $2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{g})$
- b**    During complete combustion, all of the carbon in fuel is oxidised to carbon dioxide. During incomplete combustion, carbon and carbon monoxide are produced as well as, or in place of, carbon dioxide.

**A15.**

- a**    Incomplete combustion means that not all of the carbon in the fuel is converted to carbon dioxide. Some carbon monoxide and/or some carbon are produced instead.
- b**    Incomplete combustion occurs when there is insufficient oxygen or when the combustion temperature is not high enough for the reaction to be completed.
- c**    carbon dioxide
- d**    CO combines with haemoglobin in the blood more readily than does oxygen. Less oxygen is transported to the cells and respiration cannot take place at the required rate.
- e**     $\text{C}_7\text{H}_{16}(\text{g}) + 10\text{O}_2(\text{g}) \rightarrow 5\text{CO}_2(\text{g}) + 2\text{CO}(\text{g}) + 8\text{H}_2\text{O}(\text{g})$
- f**    The car should be 'tuned' correctly and more complete combustion of the fuel will reduce the CO levels.
- g**    CO acts as a poison in the body and blocks the uptake of oxygen in the bloodstream.

**A16.**

- a**    A temperature inversion is a layer of cold air trapped under a layer of warm air.
- b**    Cold air is more dense than warm air and so cannot rise up past the layer of warm air. Any primary pollutants in the cold air are trapped and, therefore, have more time to react in the presence of sunlight to produce photochemical smog.

**A17.**

When vehicles are accelerating, more fuel is burnt and higher engine temperatures are reached. This favours the formation of nitrogen oxides.

**A18.**

The reduction in car traffic reduces the combustion of fuels and other chemicals by cars, and reduces the levels of pollutants in the atmosphere.

**A19.**

- a**    octane, oxygen, nitrogen
- b**    **i**     $2\text{C}_8\text{H}_{18}(\text{g}) + 25\text{O}_2(\text{g}) \rightarrow 16\text{CO}_2(\text{g}) + 18\text{H}_2\text{O}(\text{g})$   
      **ii**    $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$  then  $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$   
       $a\text{C}_8\text{H}_{18}(\text{g}) + b\text{O}_2(\text{g}) \rightarrow c\text{CO}(\text{g}) + d\text{CO}_2(\text{g}) + e\text{H}_2\text{O}(\text{g})$   
      **iii**   For efficient combustion of petrol, there should be a slight excess of air so that the fuel is oxidised completely, giving maximum energy and minimum amounts of carbon monoxide and unburnt hydrocarbons in the emissions. However, excess air provides more oxygen to react with nitrogen at the high engine temperatures, thus increasing emissions of nitrogen oxides.

**A20.**

- a**    An increase in the average temperature of the Earth, causing a change in the rainfall patterns. Sea levels will rise, flooding low-lying countries and coastal land.
- b**    Use alternative energy sources; reduce the amount of energy generated by fossil fuels.

**A21.**

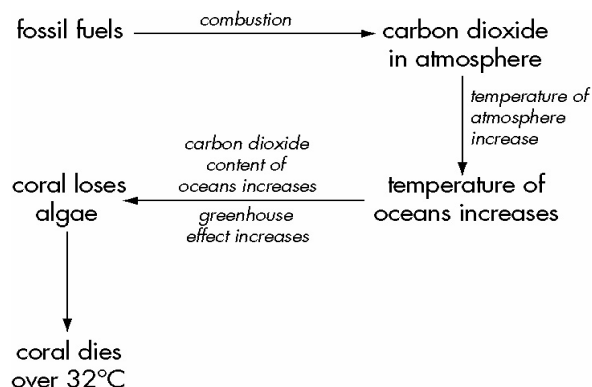
- a**    Gases tend to be less soluble as the temperature increases. As the temperature of the oceans rise, less carbon dioxide can be dissolved in the oceans.
- b**    The concentration of carbon dioxide in the atmosphere would increase, and so the temperature of the atmosphere would increase and the greenhouse effect would worsen.

**A22.**

Ozone is a pollutant at ground level because of its damaging effects on living things. The low concentrations of ozone in the stratosphere are, however, essential to life on Earth due to the fact that ozone absorbs harmful ultraviolet light. Ozone, therefore, is only a pollutant when it is 'out of place'; that is, at ground level.

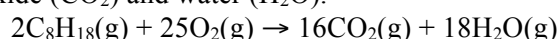
**A23.**

There will be many individual responses to this question.

**A24.**

**a** An example of a concept map.

**b** One example of combustion of a fossil fuel is burning octane ( $C_8H_{18}$ ), which produces carbon dioxide ( $CO_2$ ) and water ( $H_2O$ ).



## Chapter 20 Gases of the atmosphere

**A1.**

- a**  $HNO_3$  is the oxidant because N is reduced from 5+ to 4+.  
**b** Cu is the reductant because it is oxidised from 0 to 2+.

**A2.**

- a**  $(NH_4)_2SO_4$       **b**  $NH_4NO_3$       **c**  $NH_3$

**AE1.**

1.0 kg of  $O_2$  required =  $1000 \text{ g} / M(O_2) = 1000 \text{ g} : 32 \text{ g mol}^{-1} = 31.25 \text{ mol } O_2$  required

From the equation, 4 mol of Fe is required for 3 mol of  $O_2$  produced.

So,  $n(Fe)$  required =  $(4/3) \times 31.25 = 41.67 \text{ mol}$

So,  $m(Fe)$  required =  $n(Fe) \times M(Fe) = 41.67 \times 55.85 \text{ g} = 2327.27 \text{ g} = 2.33 \text{ kg}$

**AE2.**

$n(BaO_2) = m(BaO_2) / M(BaO_2) = 5.00 \text{ g} \div 169.33 \text{ g mol}^{-1} = 0.029 5285 \text{ mol}$

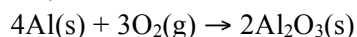
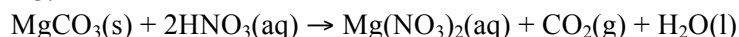
From the equation, 4 mol of  $HOCl$  reacts with 2 mol of  $BaO_2$ .

So,  $n(HOCl)$  required =  $(4 \div 2) \times 0.029 5285 = 0.059 057 \text{ mol}$

So,  $m(HOCl)$  required =  $n(HOCl) \times M(HOCl) = 0.059 057 \times 52.455 \text{ g} = 3.10 \text{ g}$

**A3.**

- a** Oxygen is required for cellular respiration, the life-sustaining process for almost all living things.  
**b**  $C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(g) + \text{energy}$

**A4.****A5.****A6.**

- a** It does not burn or support combustion, and it is denser than air.  
**b** Dry ice is solid carbon dioxide.

## Chapter review

**A7.**

- a** dispersion forces

**A8.**

**A9.**

**b** catalyst

**A10.**

$$\text{O}_2(\text{g}) + \text{O} \rightarrow \text{O}_3(\text{g})$$

**A11.**

**A12.**

**A13.**

**b**  $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$

**A14.**

$$\text{H}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightleftharpoons \text{HCO}_3^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$$

**A15.**

**A16.**

$$\text{ii} \quad 2\text{C}_4\text{H}_{10}(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{g})$$

**A17.**

$$\text{e} \quad \text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g})$$

**A18.**

c The carbon–oxygen double bond is so strong that it will not support combustion (except for magnesium) unless at very high temperatures.

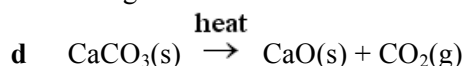
**A19.**

carbon dioxide  $\text{:}\ddot{\text{O}}=\text{C}=\ddot{\text{O}}\text{:}$

**c** Oxygen is used in the manufacture of steel and in combustion processes, such as in power stations, and



nitrogen is used in the manufacture of fertilisers and, as liquid nitrogen, for refrigeration.

**A20.**

Test a sample of each gas with a glowing taper. The gas that makes the taper glow is oxygen.

Bubble a sample of each gas into a container of limewater. The gas that turns the limewater milky is carbon dioxide. The remaining container of gas contains nitrogen.

**Chapter 21 Physical properties of gases****A1.**

- a Molecules of gases are in constant, rapid, random motion and the forces between molecules are negligible. They continue to move outwards until stopped by the walls of the container, filling all the space available.
- b Most of the volume occupied by a gas is space, so compression can be achieved by reducing the space between the particles.
- c The molecules in a gas are spread much further apart than those of a liquid. A given mass of gas would occupy a much greater volume than the same mass of the liquid phase. Therefore, the density of the gas is less.
- d Gases mix easily together because of the large amount of space between the molecules.
- e The pressure exerted by a gas depends on the number of collisions of gas particles and the wall of the container. The pressure is independent of the type of gas involved. The total pressure exerted by a mixture of gases will depend on the total number of collisions each gas has with the container.

**A2.**

- a Tyres have a recommended maximum pressure to give a comfortable ride as well as good traction on the road. If the pressure in a tyre is too high, the gas inside cannot be compressed as easily and passengers will be more aware of bumps on the road.
- b During a long journey on a hot day, the air in a tyre warms up. This means the air molecules have increased kinetic energy, and collisions with the walls of the tyres will increase, and so the pressure will increase.
- c Particles from the cooking food escape the pot and move randomly through the house. If the food has an odour, and if there are enough particles in the air, you will detect the odour as you enter the house.
- d As air is pumped into a balloon, air molecules collide with the rubber of the balloon, forcing it to expand. If too much air is pumped in, the balloon reaches a stage where it cannot stretch any further. If the number of collisions by molecules per given surface area is increased still further, the rubber will break.

**A3.**

When an air-filled tyre passes over a bump in the road, the air molecules inside the tyre move and so absorb some of the shock. A solid rubber tyre can distort and absorb some shock, but is not as effective as an air-filled tyre.

**A4.**

The peak of the graph would be higher and closer to the Y-axis.

**A5.**

These conversions should be applied as needed:

$$760 \text{ mmHg} \xrightarrow{\frac{1.00 \text{ atm}}{760}} 1.00 \text{ atm} \xrightarrow{\frac{101.3 \text{ kPa}}{1.013 \text{ atm}}} 101.3 \text{ kPa} \xrightarrow{\frac{1000 \text{ Pa}}{1.013 \text{ kPa}}} 1.013 \times 10^5 \text{ Pa} \xrightarrow{\frac{100000 \text{ Pa}}{1.013 \text{ bar}}} 1.013 \text{ bar}$$

- a  $1400 \text{ mmHg} = 1.84 \text{ atm} = 1.87 \times 10^5 \text{ Pa} = 1.87 \text{ bar}$
- b  $80\,000 \text{ Pa} = 0.790 \text{ atm} = 600 \text{ mmHg} = 0.800 \text{ bar}$
- c  $4.24 \text{ atm} = 3220 \text{ mmHg} = 4.30 \times 10^5 \text{ Pa}$
- d  $120 \text{ kPa} = 900 \text{ mmHg} = 1.18 \text{ atm} = 1.20 \text{ bars}$
- e  $140 \text{ kPa} = 140 \times 1000 \text{ Pa} = 1.40 \times 10^5 \text{ Pa}$
- f  $92\,000 \text{ Pa} = 92 \text{ kPa}$

**A6.**

Use these conversions:  $1 \text{ mL} = 1 \text{ cm}^3$ ,  $1 \text{ L} = 1 \text{ dm}^3$ ,  $1 \text{ L} = 1000 \text{ mL} = 1000 \text{ cm}^3$ ,  $1 \text{ m}^3 = 10^3 \text{ dm}^3 = 10^6 \text{ cm}^3$

- a  $2 \text{ L} = 2 \times 10^3 \text{ mL}$
- b  $4.5 \text{ dm}^3 = 4.5 \times 10^3 \text{ mL}$
- c  $2250 \text{ mL} = 2.25 \text{ L}$
- d  $120 \text{ mL} = 0.12 \text{ L}$
- e  $56 \text{ mL} = 5.6 \times 10^{-2} \text{ L}$
- f  $3.7 \text{ dm}^3 = 3.7 \times 10^{-3} \text{ m}^3$

**g**  $285 \text{ mL} = 2.85 \times 10^{-4} \text{ m}^3$     **h**  $4.70 \times 10^{-3} \text{ m}^3 = 4.70 \times 10^3 \text{ cm}^3$

**A7.**

- a** As temperature increases, the average kinetic energy of gas molecules in the can will increase. This will lead to an increase in the frequency and force of collisions of gas molecules with the inside walls of the aerosol cans. This will cause an increase in pressure.
- b** As the syringe is compressed, the inside surface area of the syringe will decrease. The number of collisions of molecules per unit area per second with the inside walls of the syringe will increase. This will cause a pressure increase.

**A8.**

**a**  $V_2 = 25 \text{ L}$                       **b**  $V_2 = 29 \text{ L}$                       **c**  $V_2 = 2.3 \times 10^3 \text{ cm}^3$  or  $2.3 \text{ L}$   
**d**  $P_2 = 85.3 \text{ kPa}$

**A9.**

Remember to use Boyle's law:  $P_1V_1 = P_2V_2$ . Each of the pressure and volume units needs to be the same.

**a**  $V_2 = 60 \text{ mL}$                       **b**  $V_2 = 267 \text{ mL}$                       **c**  $V_2 = 188 \text{ mL}$

**A10.**

Remember to use Boyle's law:  $P_1V_1 = P_2V_2$ . Each of the pressure and volume units needs to be the same.  
 $V_2 = 3.5 \text{ mL}$

**A11.**

Remember to use Boyle's law:  $P_1V_1 = P_2V_2$ . Each of the pressure and volume units needs to be the same.  
 $P_2 = 320 \text{ Pa}$

**A12.**

Remember to convert temperatures by using:  $T = t + 273$ , where  $T$  is the absolute temperature (in kelvin), and  $t$  is the temperature on the Celsius scale. It is also conventional not to use the degree symbol when writing the absolute temperature. For example,  $25^\circ\text{C}$  would be written as  $298 \text{ K}$ .

**a**  $T = 100 + 273 = 373 \text{ K}$     **b**  $T = 175 + 273 = 448 \text{ K}$     **c**  $T = -145 + 273 = 128 \text{ K}$

**A13.**

**a i**  $V_2 = 120 \text{ mL}$                       **ii**  $V_2 = 55 \text{ mL}$   
**b i**  $T_2 = 99 \text{ K}$  or  $-174^\circ\text{C}$     **ii**  $T_2 = 397 \text{ K}$  or  $124^\circ\text{C}$

**A14.**

**a**  $n(\text{methane}) = 1600 \text{ mol}$     **b**  $m(\text{methane}) = 1600 \times 16 \text{ g} = 25.6 \text{ kg}$

**A15.**

$V_2 = 7.1 \text{ L}$

**A16.**

**a**  $V(\text{Cl}_2) = 24.5 \times 1.4 = 34 \text{ L}$                       **b**  $V(\text{H}_2) = 24.5 \times 1.0 \times 10^{-3} \text{ L} = 2.5 \times 10^{-2} \text{ L} = 25 \text{ mL}$   
**c**  $V(\text{N}_2) = 1.2 \text{ L}$

**A17.**

**a**  $n(\text{Ne}) = 0.114 \text{ mol}$  so  $m(\text{Ne}) = 0.114 \times 20.1 = 2.3 \text{ g}$   
**b**  $n(\text{O}_2) = 2.04 \text{ mol}$  so  $m(\text{O}_2) = 2.04 \times 32.0 = 65 \text{ g}$   
**c**  $n(\text{CO}_2) = 0.0057 \text{ mol}$  so  $m(\text{CO}_2) = 0.0057 \times 44.0 = 0.251 \text{ g}$

**A18.**

**a**  $V_2 = 13.2 \text{ L}$                       **b**  $V_2 = 33.3 \text{ L}$                       **c**  $V_2 = 35.8 \text{ L}$

**A19.**

$V_2 = 1023 \text{ L}$

**A20.**

$P_2 = \frac{P_1V_1T_2}{T_1V_2} = 160 \text{ kPa}$

**A21.**

$$T_2 = 1099 \text{ K or } 826^\circ\text{C} = 830^\circ\text{C (to 2 significant figures)}$$

**A22.**

$$P = 116 \text{ kPa}$$

**A23.**

$$n(\text{He}) = 4.19 \text{ mol so } m(\text{He}) = 4.19 \times 4.0 = 16.8 \text{ g}$$

**A24.**

The general gas equation needs to be used:  $PV = nRT$ . Temperature should be in kelvin, pressure in kPa and volume in L.  $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$ .

$$\text{a } V = 4.5 \text{ L} \quad \text{b } V = 87 \text{ L} \quad \text{c } V = 6.23 \text{ L}$$

**A25.**

$$T = \frac{102 \times 10.0 \times 28.0}{11.3 \times 8.31} = 304 \text{ K} = 31.1^\circ\text{C}$$

**A26.**

$$n(\text{N}_2) = 0.155 \text{ mol and } n(\text{He}) = 0.123 \text{ mol so there is a greater amount of nitrogen.}$$

**A27.**

- a  $n(\text{Mg}) = 0.10 \text{ mol and } n(\text{H}_2) = n(\text{Mg}) \text{ so } V(\text{H}_2) = 24.5 \times 0.10 = 2.45 \text{ L}$   
 b  $n(\text{Mg}) = 0.022 \text{ mol so } V(\text{H}_2) = 24.5 \times 0.022 \text{ L} = 0.54 \text{ L}$   
 c  $n(\text{Mg}) = 0.000\,074 \text{ mol so } V(\text{H}_2) = 24.5 \times 0.000\,074 \text{ L} = 0.0018 \text{ L or } 1.8 \text{ mL}$   
 d  $n(\text{Mg}) = 0.0658 \text{ mol so } V(\text{H}_2) = 24.5 \times 0.0658 \text{ L} = 1.61 \text{ L}$

**A28.**

- a i  $n(\text{C}_3\text{H}_8) = 0.50 \text{ mol and } \frac{n(\text{O}_2)}{n(\text{C}_3\text{H}_8)} = \frac{5}{1} \text{ so } V(\text{O}_2) = 5 \times 0.50 \times 24.5 = 61 \text{ L}$   
 ii  $\frac{n(\text{CO}_2)}{n(\text{C}_3\text{H}_8)} = \frac{3}{1} \text{ so } V(\text{CO}_2) = 3 \times 0.50 \times 24.5 = 37 \text{ L}$   
 b i  $n(\text{C}_3\text{H}_8) = 0.114 \text{ mol so } V(\text{O}_2) = 5 \times 0.114 \times 24.5 = 14 \text{ L}$   
 ii  $V(\text{CO}_2) = 3 \times 0.114 \times 24.5 = 8.4 \text{ L}$   
 c i  $n(\text{C}_3\text{H}_8) = 0.0033 \text{ mol so } V(\text{O}_2) = 5 \times 0.0033 \times 24.5 = 0.404 \text{ L}$   
 ii  $V(\text{CO}_2) = 3 \times 0.0033 \times 24.5 = 0.242 \text{ L}$   
 d i  $n(\text{C}_3\text{H}_8) = 0.375 \text{ mol so } V(\text{O}_2) = 5 \times 0.375 \times 24.5 = 45.9 \text{ L}$   
 ii  $V(\text{CO}_2) = 3 \times 0.375 \times 24.5 = 27.6 \text{ L}$   
 e i  $n(\text{C}_3\text{H}_8) = 77.3 \text{ mol so } V(\text{O}_2) = 5 \times 77.3 \times 24.5 = 9500 \text{ L}$   
 ii  $V(\text{CO}_2) = 3 \times 77.3 \times 24.5 = 5700 \text{ L}$

**A29.**

The balanced equation shows that 2 mol of octane produces 16 mol of carbon dioxide.

$$n(\text{CO}_2) = 1.70 \text{ mol}$$

$$\text{If } \frac{n(\text{C}_8\text{H}_{18})}{n(\text{CO}_2)} = \frac{2}{16} \text{ then } n(\text{C}_8\text{H}_{18}) = 2 / 16 \times n(\text{CO}_2) = 0.213 \text{ mol}$$

$$\text{So } m(\text{C}_8\text{H}_{18}) = n(\text{C}_8\text{H}_{18}) \times M = 0.213 \times 114 = 24.2 \text{ g}$$

**A30.**

The balanced equation shows that 2 mol of  $\text{NO}_2$  is produced from 2 mol of  $\text{NO}$ . Therefore, the volumes of gases produced will be equal to the volume of  $\text{NO}$  reacted (as long as the temperature and pressure are constant)  $\therefore V(\text{NO}) = V(\text{NO}_2) = 0.5 \text{ L}$

**A31.**

The balanced equation shows that 1 mol of  $\text{O}_2$  reacts with 2 mol of  $\text{CO}$ . Therefore, the volumes of  $\text{O}_2$  and  $\text{CO}$  used also will be in the ratio 1 : 2 (as long as the temperature and pressure are constant).

$$\therefore V(\text{CO}) = 150 \text{ mL} \quad \therefore V(\text{O}_2) = 75 \text{ mL}$$

**A32.**

The balanced equation shows that 1 mol of  $\text{Cl}_2$  reacts with 1 mol of  $\text{H}_2$ , producing 2 mol of  $\text{HCl}$ . All of the 3.0

L of hydrogen will react, using up 3.0 L of chlorine. So there will be 4.0 L of chlorine in excess. A total of 6.0 L of HCl will be produced.  $\therefore$  final volume =  $4.0 + 6.0 = 10.0$  L

## Chapter review

### A33.

Gases are composed of small particles (atoms or molecules). The volume of the particles themselves is very much smaller than the volume occupied by the gas. The particles move in a rapid, straight-line motion and collide with each other and with the walls of the container. The forces between particles are extremely weak. The collisions between particles are elastic. The average kinetic energy of the particles is directly proportional to the kelvin temperature of the gas.

### A34.

- a As volume is reduced, there is an increase in the frequency of molecular collisions per unit wall area. This is measured as an increase in pressure.
- b When the temperature of a gas is lowered, the average kinetic energy of the particles decreases. The rate of collisions between particles and the walls of the container decreases and particles collide with less force. As pressure is a measure of the force of molecular collisions per unit wall area of the container, pressure is found to decrease.
- c In a mixture of gases, the particles of each gas are moving and colliding with the walls of the container, independently of each other. Each gas therefore exerts a pressure. As the gases behave independently of each other, total pressure is simply the sum of the individual gas (or partial) pressures.
- d When more gas is added to a container, the total number of particles in the container increases. Provided that the volume of the container and the temperature have not changed, the collisions of these additional particles means that the total pressure in the container has increased.

### A35.

- a The pressure also increases inside the diver's body.
- b The pressure inside the lungs is high. Under these conditions, expansion of the lungs can cause injury.
- c The 'bends' are caused by gases, mainly nitrogen, coming out of solution in a diver's blood when he or she ascends from a dive too rapidly. The gas can form small bubbles in joints, muscle and other tissue, causing serious injury and great pain. To treat the bends, a diver is placed in a decompression chamber and the pressure is increased until nitrogen bubbles re-dissolve in the blood. Pressure is then slowly reduced to one atmosphere.
- d The longer a diver stays down on a dive, the more nitrogen will dissolve in the blood and the slower the ascent will need to be to avoid problems from the bends.

### A36.

- a The pressure inside the container is reduced when some of the gas escapes.
- b There are fewer gas molecules to collide with each other and the walls of the container. Pressure is the force exerted by the molecules over a defined area, so this will decrease.

### A37.

Astronauts need to be protected from the very low temperatures and pressures. Without a pressurised space suit, all air would rapidly escape from their lungs and they would die from lack of oxygen. Body tissue would also freeze after a short time.

### A38.

The gas particles can mix fully at any concentration and move in any direction to fill a container of any size. Particles in an aqueous solution are confined to a specific volume and have a limit to their solubility in each other.

### A39.

- a There appears to be no upper limit to the temperature scale since particles can move to very high speeds. The speed of a particle is related to its kinetic energy, which is related to the temperature of the surrounds.
- b A plot of volume against temperature for a gas provides a straight-line graph, which intersects the temperature axis at a certain point. This point is called the absolute zero of temperature. Because this graph can be drawn, it is possible to define absolute zero.

**A40.**

Remember to use Boyle's law:  $P_1V_1 = P_2V_2$ . Each of the pressure and volume units needs to be the same. This conversion should be applied as needed: 1 L = 1000 mL.

**a**  $P_2 = 300 \text{ kPa}$

**b**  $P_2 = 38 \text{ kPa}$

**c**  $P_2 = 7.5 \text{ kPa}$

**A41.**

$P_2 = 10 \text{ kPa}$

Gas from the 4 L cylinder will spread into the 6 L volume.

In the 4 L cylinder:  $P_2 = 40 \text{ kPa}$  so the new total pressure =  $10 + 40 = 50 \text{ kPa}$ .

**A42.**

$V_2 = 8.2 \text{ L}$

**A43.**

$T_2 = 315 \text{ K}$  or  $42^\circ\text{C}$

**A44.**

$V_2 = 698 \text{ L}$

**A45.**

$V_2 = 866 \text{ L}$

**A46.**

$T_2 = 73 \text{ K}$  or  $-200^\circ\text{C}$

**A47.**

$n(\text{H}_2) = 0.50 \text{ mol}$

$n(\text{O}_2) = 0.063 \text{ mol}$

$V_2 = 1.2 \text{ L}$

**A48.**

Number of  $\text{CO}_2$  molecules =  $1.6 \times 10^{24}$  molecules.

**A49.**

**a** Molecules of real gases have a small but finite volume; those of ideal gases are assumed to be point particles. There are some forces of attraction between molecules of real gases, whereas it is assumed there are none between those of ideal gases.

**b** ammonia; hydrogen bonding exists between molecules

**A50.**

**a** As temperature rises, the volume of a gas increases. Therefore, the same mass of gas occupies a greater volume at a higher temperature.

Because density = mass/volume, the higher the temperature, the larger the volume and the lower the density.

**b** As the temperature of a gas increases, the average kinetic energy of molecules increases. However, there will still be some molecules at the higher temperature with low kinetic energy.

**A51.**

$n = 0.241 \text{ mol}$  so Number of particles =  $n \times N_A = 0.241 \times 6.02 \times 10^{23} \text{ molecules} = 1.45 \times 10^{23} \text{ molecules}$

**A52.**

$V = 5.56 \text{ L}$

**A53.**

$n(\text{O}_2) = 0.431 \text{ mol}$  so  $m(\text{O}_2) = 0.431 \times 32 = 13.8 \text{ g}$

**A54.**

$n(\text{He}) = 0.050 \text{ mol}$  so  $T = 770 \text{ K}$

**A55.**

The general gas equation needs to be used:  $PV = nRT$ . Temperature should be in kelvin, pressure in kPa and volume in L.  $R = 8.31 \text{ J K}^{-1} \text{ mol}^{-1}$ .

**a**  $n = 0.217 \text{ mol}$

**b**  $M = 46.2 \text{ g mol}^{-1}$

**A56.**

$n(\text{O}_2) = 1.65 \text{ mol}$                       Container B:  $n(\text{O}_2) = 0.0020 \text{ mol}$  so Container A has more oxygen.

**A57.**

**a** Conversions are:  $220 \text{ m}^3 = 220 \times 10^3 \text{ dm}^3 = 220 \times 10^3 \text{ L}$

$n(\text{air particles}) = 8940 \text{ mol}$

**b**  $n(\text{O}_2) = 1788 \text{ mol}$  so  $m(\text{O}_2) = 1788 \times 32 = 57.2 \text{ kg}$

80% of the room is nitrogen so  $n(\text{N}_2) = 7152 \text{ mol}$  and  $m(\text{N}_2) = 7152 \times 28 = 200 \text{ kg}$

Total mass of gas =  $57.2 + 200 = 257 \text{ kg}$

**A58.**

**a**  $V(\text{O}_2) = 6.1 \text{ L}$

**b**  $n(\text{NO}_2) = \frac{V}{V_m} = 0.408 \text{ mol}$  so  $m(\text{NO}_2) = 0.408 \times 46 = 18.7 \text{ g}$

**A59.**

**a** At SLC, molar volume is  $24.5 \text{ L}$  so Number of molecules =  $\frac{5.0}{24.5} \times N_A = 1.2 \times 10^{23}$

**b** At SLC, molar volume is  $24.5 \text{ L}$  so Number of molecules =  $2.46 \times 10^{24}$

**c** At SLC, molar volume is  $24.5 \text{ L}$  so Number of molecules =  $2.4 \times 10^{20}$

**d** At STP, molar volume is  $22.4 \text{ L}$  so Number of molecules =  $2.7 \times 10^{20}$

**e** At STP, molar volume is  $22.4 \text{ L}$  so Number of molecules =  $2.7 \times 10^{25}$

**f** At STP, molar volume is  $22.4 \text{ L}$  so Number of molecules =  $\frac{156}{22.4} \times N_A = 4.2 \times 10^{24}$

**A60.**

**a** The molar mass of  $\text{CO}_2 = 44 \text{ g mol}^{-1}$  and  $m = n \times M$  so  $m(\text{CO}_2) = 1 \times 44 = 44 \text{ g}$

**b** The volume of any gas at SLC =  $24.5 \text{ L}$ .

**c** Density ( $\text{CO}_2$ ) =  $1.8 \text{ g L}^{-1}$                       **d** Greater, because volume decreases as temperature decreases.

**A61.**

The balanced equation shows that 1 mol of methane reacts with 2 mol of oxygen to give 1 mol of carbon dioxide, and 2 mol of water. At constant temperature and pressure, mole and volume are directly proportional to each other.

**a**  $\therefore V(\text{CH}_4) \text{ used} = 5 \text{ L}$                       **b**  $\therefore V(\text{O}_2) \text{ used} = 10 \text{ L}$

**c**  $\frac{n(\text{H}_2\text{O})}{n(\text{CO}_2)} = \frac{2}{1}$  so  $n(\text{H}_2\text{O}) = 2 \times n(\text{CO}_2) = 0.254 \text{ mol}$  and  $m(\text{H}_2\text{O}) = 0.254 \times 18 = 4.58 \text{ g}$

**A62.**

**a**  $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$                       **b**  $n(\text{CaCO}_3) = 0.20 \text{ mol}$                       **c**  $V = 0.20 \times 24.5 = 4.9 \text{ L}$

**A63.**

**a** The balanced equation shows that the mole ratio of propane to oxygen is 1 : 5. All temperatures and pressures are the same, therefore mole and volume are directly proportional to each other.

$\therefore$  80 mL of propane would need 400 mL of oxygen to react completely, and 500 mL of oxygen would need 100 mL of propane to react completely.

$\therefore$  There is excess oxygen, which means that all of the propane will react, and that there will be 100 mL of oxygen in excess.

**b**  $V(\text{CO}_2) = 3 \times 80 = 240 \text{ mL}$                        $V(\text{H}_2\text{O}) = 4 \times 80 = 320 \text{ mL}$

**c** The original volume of gases =  $80 + 500 = 580 \text{ mL}$

The final volume of gases =  $100 + 240 + 320 = 660 \text{ mL}$  so there was an increase in volume of 80 mL.

**A64.**

**a**  $2\text{Al}(\text{s}) + 6\text{HCl}(\text{aq}) \rightarrow 2\text{AlCl}_3(\text{aq}) + 3\text{H}_2(\text{g})$

**b**  $n(\text{Al}) = 0.0089 \text{ mol}$  so  $n(\text{H}_2) = 0.013 \text{ mol}$  so  $V = 0.32 \text{ L}$

**A65.**

The balanced equation is:

$\text{CaCO}_3(\text{s}) + 4\text{H}_2(\text{g}) \rightarrow \text{CH}_4(\text{g}) + \text{Ca}(\text{OH})_2(\text{s}) + \text{H}_2\text{O}(\text{g})$

**a** When temperature and pressure are constant, mole and volume are directly proportional to each other.

∴ The volume of methane produced will be  $\frac{1}{4}$  the volume of hydrogen used.

∴ The volume of methane will be 25 L.

- b**  $n(\text{H}_2) = 1.79 \text{ mol}$  so  $n(\text{CaCO}_3) = 0.447 \text{ mol}$   
 $m(\text{CaCO}_3) = nM = 0.447 \text{ mol} \times 100 \text{ g mol}^{-1} = 44.7 \text{ g}$

**A66.**

- a**  $n = 4.07 \times 10^{-5} \text{ mol}$  so Number of molecules  $= nN_A = 4.07 \times 10^{-5} \times 6.02 \times 10^{23} = 2.5 \times 10^{19}$   
**b** Number of collisions for each molecule  $= 6.1 \times 10^9$   
**c** The average kinetic energy of the hydrogen molecules remains constant as long as temperature is constant. However, the actual kinetic energy of any one hydrogen molecule could vary significantly over time.  
**d** Place a sample of gas in a thermally insulated container. Use a sensitive temperature probe to monitor the temperature of the gas over time. If collisions are not elastic, the average kinetic energy of the molecules and, hence, the temperature of the gas, would decrease with time.  
**e** If there were no forces between particles in the gaseous state there would be little tendency for particles to come together and form liquids. A substance, once in its gaseous state, would remain in that state.

**A67.**

- a** Equal. Average kinetic energy is proportional to the temperature of the gas, and at the same temperature is not dependent on the particular gas, so they will be equal.  
**b** Oxygen. As average kinetic energy  $= \frac{1}{2}mv^2$ , the lighter gas particles will have the greater average velocity.  $M(\text{O}_2) = 32 \text{ g mol}^{-1}$ ,  $M(\text{CO}_2) = 44 \text{ g mol}^{-1}$ . So the oxygen molecules will have the greater average velocity.  
**c** Equal. With pressure, volume and temperature the same,  $n$  will be the same.  
**d** Carbon dioxide. Each  $\text{CO}_2$  molecule contains 3 atoms and each  $\text{O}_2$  molecule contains 2 atoms. As there are an equal amount of molecules of each gas, there are more atoms in the  $\text{CO}_2$  sample.  
**e** Carbon dioxide. Density  $= \text{mass} \div \text{volume}$ . The volume is the same for each gas, but the mass of  $\text{CO}_2$  is greater, so it has the greater density.

## Unit 2 Area of Study 2

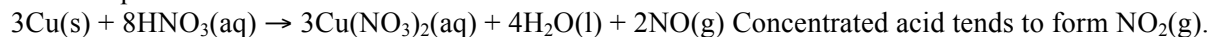
### Multiple-choice questions

**A1.**

A. This response is incorrect because oxygen is removed from the air during the process of decomposition.

**A2.**

D. The equation for the reaction is:



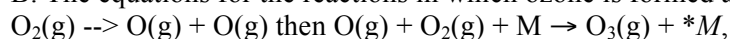
**A3.**

B. See the following table, which shows the composition of clean, dry air near sea level.

Gas	Content by amount (mol %)	Total mass in atmosphere ( $\times 10^{12}$ tonnes)
Nitrogen	78.09	3900
Oxygen	20.94	1200
Argon	0.93	6.7
Carbon dioxide	0.035	2.5
Neon	0.0018	0.065
Helium	0.00052	0.004
Methane	0.00015	0.0042
Krypton	0.0001	0.017
Carbon monoxide	0.00001	0.0006
Ozone	0.000002	0.003
Nitrogen dioxide	0.0000001	0.000013
Others	Very small amounts	

**A4.**

B. The equations for the reactions in which ozone is formed are:



where  ${}^*\text{M}$  is a molecule that takes up energy released in the second reaction.



**A5.**

D. Photochemical smog is formed from the interaction of sunlight with a mixture of oxides of nitrogen and unburned hydrocarbons.

**A6.**

D. A, B and C are tests for, respectively, ammonia, oxygen and hydrogen.

**A7.**

D. Because in a gas the particles are widely separated, gases are compressible. As the volume of the gas decreases, the particles are forced closer together, so there are more collisions of particles per second with the vessel wall, and so pressure will increase.

**A8.**

D. Volume is inversely proportional to pressure under these conditions. If the pressure is halved, the volume will double.

**A9.**

C

$$P(\text{O}_2) = \text{mole fraction of O}_2 \times \text{total pressure} = 0.625 \times 800 = 500 \text{ kPa}$$

**A10.**

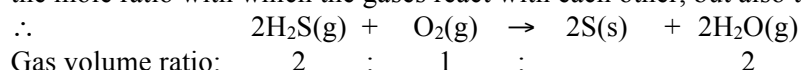
B

$$n = 2.00 \text{ mol so } P = 200 \text{ kPa}$$

**A11.**

C

Step 1: Since all measurements are made at the same temperature and pressure, the equation gives us not only the mole ratio with which the gases react with each other, but also the volume ratio.



Gas volume ratio: 2 : 1 : 2

$$\text{So } V(\text{O}_2) = 50.0 \text{ mL}$$

But there is only 25.0 mL  $\text{O}_2$  available, so  $\text{H}_2\text{S}$  is in excess. Therefore, to calculate the volume of water produced we must work from the volume of  $\text{O}_2$ .

$$V(\text{H}_2\text{O}) = 2 \times V(\text{O}_2) = 2 \times 25.0 = 50.0 \text{ mL}$$

**A12.**

B. The volume of a gas is proportional to the temperature (in kelvin) but inversely proportional to the pressure. In this situation the two effects cancel, so the volume remains at 4.0 L.

**A13.**

A. All four gases listed are significant greenhouse gases because they absorb infrared radiation given out from the Earth's surface. The gas that absorbs most ultraviolet radiation in the stratosphere is ozone.

**A14.**

C. Nitrogen fixation is the process whereby nitrogen from the air is converted into a form (e.g. nitrates or ammonium compounds) that can be absorbed by plants.

**A15.**

C. A is a liquid, so particles will be closer together than in gas B. The temperature is the same in both containers, so the kinetic energy ( $\frac{1}{2}mv^2$ ) will be the same for the particles in each container. Since the mass of molecules of A is less than that of molecules of B, the average velocity of molecules of A must be greater than that for molecules of B.

**A16.**

B. At the lower temperature, there are more molecules with a lower kinetic energy.

**A17.**

A. Volume is inversely proportional to pressure.

**A18.**

C. Since all measurements are made at the same temperature and pressure, the equation gives us not only the

mole ratio with which the gases react with each other, but also the volume ratio. Oxygen is the limiting reagent. So after the reaction, there will be no oxygen remaining.

10 mL carbon dioxide is produced.

20 mL of water vapour is produced.

10 mL methane is unreacted. So total amount of gas after the reaction = 40 mL.

### Short-answer questions

#### A19.

- a**
- i** Oxygen is required for the process of respiration in living things—plant and animal.
  - ii** Ozone in the stratosphere absorbs harmful ultraviolet radiation, which can have a damaging effect on living things.
  - iii** Water vapour in the atmosphere plays a vital part in our weather patterns. Water is essential to living things.
  - iv** Carbon dioxide is used by green plants to make their food in the process of photosynthesis.
- b** The greenhouse effect is the warming of the Earth's atmosphere by solar radiation being trapped in the Earth's atmosphere. Life on Earth depends on the greenhouse effect to maintain the Earth at a moderate temperature.
- Global warming is a slow but steady increase in the average temperatures of the Earth's atmosphere caused by an enhanced greenhouse effect. This, in turn, has been caused by an increase in the proportion of greenhouse gases, such as carbon dioxide, in the atmosphere.

#### A20.

- a**  $2\text{C}_8\text{H}_{18}(\text{g}) + 25\text{O}_2(\text{g}) \rightarrow 16\text{CO}_2(\text{g}) + 18\text{H}_2\text{O}(\text{l})$
- b**  $2\text{C}_8\text{H}_{18}(\text{g}) + 17\text{O}_2(\text{g}) \rightarrow 16\text{CO}(\text{g}) + 18\text{H}_2\text{O}(\text{l})$
- Balanced equations that contain mixtures of CO and C or CO<sub>2</sub> as products are also acceptable.
- c**  $\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g})$
- d**  $2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g})$
- e** Oxides of nitrogen and unburned hydrocarbons react in the presence of sunlight to form photochemical smog.

#### A21.

- a** Diffusion is the process by which a gas will spread throughout the space available to it, due to the random motion of the particles of the gas.
- b** The molar mass of ammonia is  $17 \text{ g mol}^{-1}$  and of hydrogen sulfide is  $34 \text{ g mol}^{-1}$ . In this situation, the temperature of the gases is the same, so the kinetic energy of their molecules ( $= \frac{1}{2}mv^2$ ) is the same. Since the mass of ammonia molecules is less than that of hydrogen sulfide molecules, the velocity of ammonia molecules must be greater than that of hydrogen sulfide molecules. Therefore, it could be expected that ammonia molecules would spread more quickly than hydrogen sulfide molecules.
- c**
- i** The individual particles of gases are completely separated from each other and are in a constant state of random motion. All particles will collide with the inside walls of the cylinder, but will do this independently of each other. The partial pressure of methane is that proportion of the total pressure that is caused by the particles of methane colliding with the cylinder walls.
  - ii** Mole fraction  $= \frac{n(\text{CH}_4)}{\text{total moles of gas}} = \frac{1.50}{1.50 + 4.50} = 0.250$
- Partial pressure = mole fraction  $\times$  total  $P = 0.250 \times 500 = 125 \text{ kPa}$

#### A22.

- a**  $\text{MgCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{MgCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
- b**  $n(\text{CO}_2) = V/24.5 = 2.60/24.5 = 0.106 \text{ mol}$
- c**  $n(\text{MgCO}_3) = n(\text{CO}_2) = 0.106 \text{ mol}$   
 $m(\text{MgCO}_3) = n \times M = 0.106 \times 84.3 = 8.95 \text{ g}$
- d**  $\% \text{MgCO}_3 = 8.95/12.8 \times 100 = 69.9\%$
- e** When carbon dioxide is bubbled through a solution of limewater, the solution will turn 'milky' due to the formation of a precipitate of calcium carbonate.  
 $\text{Ca}(\text{OH})_2(\text{aq}) + \text{CO}_2(\text{g}) \rightarrow \text{CaCO}_3(\text{s}) + \text{H}_2\text{O}(\text{l})$
- f** Photosynthesis:  $6\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l}) \rightarrow \text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) + 6\text{O}_2(\text{g})$

or dissolving in oceans, lakes, etc.  $\text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{HCO}_3^-(\text{aq})$

**A23.**

$$V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{759 \times 4.01 \times 10^6 \times 303}{297 \times 764} = 4.06 \times 10^6 \text{ L}$$

**A24.**

- a** Fermentation of glucose:  $\text{C}_6\text{H}_{12}\text{O}_6(\text{aq}) \rightarrow 2\text{C}_2\text{H}_5\text{OH}(\text{aq}) + 2\text{CO}_2(\text{g})$   
 Heating limestone:  $\text{CaCO}_3(\text{s}) \rightarrow \text{CaO}(\text{s}) + \text{CO}_2(\text{g})$   
 Adding limestone to hydrochloric acid:  $\text{CaCO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) + \text{CO}_2(\text{g})$
- b** Fermentation of glucose and heating limestone.
- c** Dry ice as a refrigerant, fire extinguishers, 'fizzy' drinks, super critical carbon dioxide as a replacement for halogenated organic solvent.

**A25.**

- a**  $2\text{H}_2\text{O}_2(\text{aq}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g})$
- b** The balanced chemical equation shows the mole ratio is 2 : 2 : 1.  
 $n(\text{H}_2\text{O}_2) = 0.294 \text{ mol}$  and  $n(\text{O}_2) = \frac{1}{2} \times 0.294 = 0.147 \text{ mol}$   
 $V = 3.68 \text{ L}$
- c**  $\text{H}_2\text{O}_2(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{HO}_2^-(\text{aq}) + \text{H}_3\text{O}^+(\text{aq})$

**A26.**

- a**  $\text{SO}_3(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_2\text{SO}_4(\text{aq})$
- b** Sulfuric acid is described as a diprotic acid because it can donate two protons to a base such as water. The equations that show this are:  $\text{H}_2\text{SO}_4(\text{l}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{HSO}_4^-(\text{aq})$   
 followed by:  $\text{HSO}_4^-(\text{aq}) + \text{H}_2\text{O}(\text{l}) \rightarrow \text{H}_3\text{O}^+(\text{aq}) + \text{SO}_4^{2-}(\text{aq})$   
 Sulfuric acid is a strong acid because the first of these reactions proceeds to completion, that is,  $\text{H}_2\text{SO}_4$  donates a proton readily ( $\text{HSO}_4^-$  is a much weaker acid).
- c** The balanced chemical equation shows the mole ratio is 1 : 1 : 1. At SLC, 1 mol of any gas has a volume of 24.5 L. Calculate the amount using  $n = \frac{V}{V_m}$ . Remember that  $1 \text{ dm}^3 = 1 \text{ L}$ .
- i**  $n(\text{SO}_3) = 0.0686 \text{ mol}$
- ii**  $n(\text{H}_2\text{SO}_4) = n(\text{SO}_3)$  and  $[\text{H}_2\text{SO}_4] = 0.0457 \text{ M}$
- iii** If the sulfuric acid is completely ionised, the  $[\text{H}_3\text{O}^+] = 2 \times [\text{H}_2\text{SO}_4]$ .  
 $\text{pH} = -\log_{10}[\text{H}_3\text{O}^+] = -\log_{10}[2 \times 0.0457] = 1.04$   
 The assumption made here is that the second stage of ionisation occurs completely.  
 If you were to assume that only the first ionisation step occurs completely, and the second not at all, then a pH of 1.34 would be calculated.

**A27.**

- a** If the compound is 82.8% carbon, then as it is a hydrocarbon, there is 17.2% hydrogen.

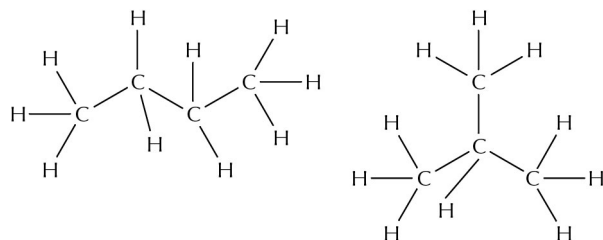
	<b>C</b>	<b>H</b>
Mass	82.8 g	17.2 g
Molar mass	12 g mol <sup>-1</sup>	1 g mol <sup>-1</sup>
Amount, using $n = m / M$	$n = 6.9 \text{ mol}$	$n = 17.2 \text{ mol}$
Divide all by smallest amount	= 1	= 2.5
Round off to whole numbers	2	5

$\therefore$  empirical formula is  $\text{C}_2\text{H}_5$

**b i**  $n = 0.0454 \text{ mol}$     **ii**  $M = 57.9 \approx 58 \text{ g mol}^{-1}$

- c** The empirical formula,  $\text{C}_2\text{H}_5$ , has a molar mass of  $24 + 5 = 29 \text{ g mol}^{-1}$ .  
 The molecule must contain a whole number of  $\text{C}_2\text{H}_5$  units.  
 Number of units in a molecule = 2  
 $\therefore$  Molecular formula has twice the number of atoms of each element as the empirical formula.  
 $\therefore$  The molecular formula is  $\text{C}_4\text{H}_{10}$ .

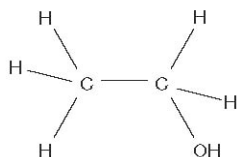
**d**

**A28.**

- a** Sodium consists of a lattice of sodium ions surrounded by a sea of electrons. There is strong metallic bonding in three dimensions throughout the lattice. Sodium chloride consists of a three-dimensional lattice of sodium cations and chloride anions held together by strong ionic bonding.
- b**  $\text{Na(g)}$  and  $\text{NaCl(g)}$  or  $\text{Na}^+(\text{g})$  and  $\text{Cl}^-(\text{g})$ .

**A29.**

- a**  $\text{C}_2\text{H}_6\text{O(l)} + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O(g)}$
- b**  $n(\text{C}_2\text{H}_5\text{OH}) = \frac{m(\text{C}_2\text{H}_5\text{OH})}{M(\text{C}_2\text{H}_5\text{OH})} = \frac{1000}{46.0} = 21.7 \text{ mol}$
- So  $n(\text{CO}_2) = 2 \times n(\text{C}_2\text{H}_5\text{OH}) = 43.5 \text{ mol}$
- $m(\text{CO}_2) = n(\text{CO}_2) \times M(\text{CO}_2) = 43.5 \times 44 = 1913 \text{ g} = 1.91 \text{ kg}$  (to 3 significant figures)
- c** 1 mol of any gas occupies 22.4 L at STP. So  $V(\text{CO}_2)$  at STP =  $22.4 \times 43.5 = 974 \text{ L}$
- d** Advantages: clean burning fuel and renewable. Disadvantages: higher cost than petrol; not recommended by some car manufacturers in quantities above 10%.
- e**

**A30.**

- a**  $A_r(\text{Mg}) = \frac{78.99 \times 23.98504 + 10.00 \times 24.98504 + 11.01 \times 25.98259}{100} = 24.3$
- b**  $\text{Mg(s)} + 2\text{HCl(aq)} \rightarrow \text{MgCl}_2(\text{s}) + \text{H}_2(\text{g})$
- c**  $n(\text{Mg}) = \frac{15.00}{24.3} = 0.617 \text{ mol}$
- d**  $V(\text{H}_2) \text{ produced} = 0.617 \times 24.5 = 15.1 \text{ L}$

**A31.**

Tonnes of greenhouse gases emitted =  $4.38 + 4.44 + 4.83 + 4.79 = 18.36$  tonnes.